GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
PROJECT ADMINISTRATION DATA SHEET

Project No./Center No. G-35-602 (R6296-0A0)
Project Director: Dr. L.T. Long
Sponsor: Law Engineering Testing Company

Agreement No.: Research Project Agreement dated 3/1/87
Award Period: From 3/1/87 To 9/1/87

Sponsor Amount:
Contract Value: $19,846
Funded: $19,846

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Cost Sharing: $NONE

Title: Analysis of Landsat Data and Testing of Hypothesis for Charleston Earthquake

ADMINISTRATIVE DATA
1) Sponsor Technical Contact:
   Robert White
   Law Engineering Testing Company
   112 Town Park Drive
   Kennesaw, GA 30144

2) Sponsor Issuing Office:
   John Dwyer
   Law Engineering Testing Company
   112 Town Park Drive
   Kennesaw, GA 30144

Military Security Classification: N/A
(or) Company/Industrial Proprietary: N/A
ONR Resident Rep. is ACO: Yes X No
Defense Priority Rating: N/A

RESTRICTIONS
See Attached N/A Supplemental Information Sheet for Additional Requirements.
Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor
approval where total will exceed greater of $500 or 125% of approved proposal budget category.
Equipment: Title vests with None proposed or anticipated.

COMMENTS:

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FORM OCA 65:1086
SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date: 11/28/88

Project No.: G-35-602 (R6296-0A0) School/Dept: Geo. Science

Includes Subproject No.(s): N/A

Project Director(s): Dr. L.T. Long

Sponsor: Law Engineering Testing Co.

Title: Analysis of Landsat Data and Testing of Hypothesis for Charleston Earthquake

Effective Completion Date: 9/1/87 (Performance) 9/1/87 (Reports)

Grant/Contract Closeout Actions Remaining:

[ ] None
[ ] Final Invoice or Copy of Last Invoice Serving as Final
[ ] Release and Assignment
[ ] Final Report of Inventions and/or Subcontract:
  Patent and Subcontract Questionnaire
  sent to Project Director [ ]
[ ] Govt. Property Inventory & Related Certificate
[ ] Classified Material Certificate
[ ] Other

Continues Project No. [ ] Continued by Project No. [ ]

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Other
Models of the stress field in a crustal section with inhomogeneous strength and elastic parameters have been submitted under separate cover to Law Environmental Incorporated. Through cooperative efforts, these were included in Chapter 7 "Local Stress Modeling" of the Project Report titled "Evaluation of Hypotheses for the Cause of the 1886 Charleston Earthquake" by Robert M. White and L. T. Long, to be submitted to the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington D.C. 20555.

A copy of Chapter 7 is attached as a summary of the work on Task III. Additional analysis can be found in the Ph.D. Thesis "Investigation of the Cause of Earthquakes in Southeastern Tennessee and Northern Georgia Using Focal Mechanisms and the Models of Crustal Stress" by Karl-Heinz Zelt, School of Geophysical Sciences, Georgia Institute of Technology, September 1988.

Submitted to:

Attn: John Dwyer
Law Environmental Incorporated
112 Town Park Drive
Kennesaw, Georgia 30144
The final geological model for the Charleston area was used as a basis for computing crustal stress in an inhomogeneous crust. The purpose of computing crustal stress was to examine the potential effects of stress amplification and concentration in a geologic model appropriate for the Charleston area. A second objective was to obtain numerical values for stress that can be used in testing hypotheses on the cause of the Charleston seismicity.

7.1 Theory of Two-Dimensional Stress Modeling

The primary considerations for modeling stress in the crust of the Coastal Plain are the larger structures within the crust. The smaller features, those with dimensions less than 5 km, would not contribute significantly to a major earthquake, which would have a fault rupture area with a diameter in excess of 25 km. Hence, the mafic intrusions, Triassic basins, and topography of the base of the rigid crust from the geologic model are the major components of the stress analysis. The stress model was designed to consider a rigid upper crust underlain by a viscoelastic lower crust and a shallowing of this viscoelastic zone suggested by the magnetotelluric data.

The stress model was computed by using a conventional two-dimensional finite-element program for elastic media. We consider this model useful for discussing relative values of stress and strength differences in the crust. A twenty-five kilometer thick portion of the crust was modeled for a distance of 128 kilometers. Within the 128 kilometers two mafic intrusives and two Triassic basins were included. For this model, we varied the depth to the base of the rigid crust from 10 to 23 km, as indicated from our MT study. The elastic constants and the general configuration are given in Figure 7-1. The viscoelastic lower crust was simulated by introducing a medium with a higher Poisson's ratio and lower Young's modulus, to compensate for the viscous dissipation of stress with time.

The boundary conditions constrained the horizontal displacement on the northwest end of the profile and applied a constant horizontal stress on the southeast end. The constant horizontal stress represents the regional plate stress. All other boundaries were free to move in response to the applied stress. Vertical forces, such as might be obtained from topography, were not considered significant for the immediate Charleston area.

The geometry of the model was taken from a profile of the geologic model presented in Chapter 5 (Section AA', Figure 5-29). This profile extends toward the northwest and passes
COASTAL PLAIN SEDIMENTS

\[ \rho = 2.2 \text{ g/cm}^3 \]
\[ V_p = 2.2 \text{ km/s} \]
\[ \sigma = 0.4 \]
\[ E = 5 \times 10^4 \text{ Pa} \]

Triassic/Jurassic SEDIMENTS

\[ \rho = 2.52 \text{ g/cm}^3 \]
\[ V_p = 4.5 \text{ km/s} \]
\[ \sigma = 0.3 \]
\[ E = 3.8 \times 10^7 \text{ Pa} \]

GABBRO

\[ \rho = 2.97 \text{ g/cm}^3 \]
\[ V_p = 6.82 \text{ km/s} \]
\[ \sigma = 0.25 \]
\[ E = 1.2 \times 10^9 \text{ Pa} \]

Granitic Crystalline Rock

\[ \rho = 2.67 \text{ g/cm}^3 \]
\[ V_p = 6.15 \text{ km/s} \]
\[ \sigma = 0.25 \]
\[ E = 8.6 \times 10^7 \text{ Pa} \]

Granitic Crystalline Rock

\[ \rho = 2.67 \text{ g/cm}^3 \]
\[ V_p = 6.23 \text{ km/s} \]
\[ \sigma = 0.40 \]
\[ E = 1.4 \times 10^9 \text{ Pa} \]

Mantle

\[ \rho = 3.07 \text{ g/cm}^3 \]
\[ V_p = 8.2 \text{ km/s} \]

Figure 7-1. Schematic cross section of typical crust in the Charleston area showing elastic constants used in two-dimensional stress modeling.
through a point approximately 10 km southwest of the Charleston epicentral zone. Because cross sections at a number of angles through our geologic model resemble the one chosen, a different compressive regional stress orientation can still be considered as applicable to our model. This would produce a different magnitude of the applied compressive stress but the relative stress differences would be similar.

The finite element mesh is shown in Figures 7-2 through 7-4. Figures 7-5 through 7-7 indicate the magnitude of the principal stress axis. Figures 7-8 through 7-10 indicate the magnitude of the maximum shear stress. The results in Figures 7-5 through 7-10 are two-dimensional and thus apply to a vertical profile in which only normal or reverse faulting could be predicted. The model in the vertical plane precludes interpretation of strike-slip faulting.

7.2 Elastic Properties of Crustal Rock

The elastic properties of rock at seismogenic depths in the Charleston area are necessary to model the response of the subsurface to applied stress. To arrive at estimates of the elastic properties, we began with the interpretation of the distribution of different rock types in the subsurface from our geologic model. Figure 7-1, a generalized section through the study area, shows the model and the elastic properties of each material. The following describes the basis for the initial parameters used in the stress model.

Coastal Plain Sediments: The gravity modeling indicated that 2.2 g/cm$^3$ is a reasonable estimate of the average density of the Coastal Plain sediments. This implies a density porosity of 25-30 percent which we find reasonable for the Coastal Plain sediments. The average compressional wave velocity of 2.2 km/s was based on refraction results, velocity logging, and seismic reflection results (Ackerman, 1983; Yantis et al., 1983). The Coastal Plain sediments are considered to be everything above the "J" seismic horizon. Comparison of compression wave velocities and densities for sediments indicate that a compressional wave velocity of 2.2 km/s is commonly associated with a density of 2.2 g/cm$^3$ (Gardner et al., 1974). A Poisson's ratio of 0.4 was based on our experience with similar sediments. Given the density, compressional wave velocity, and Poisson's ratio, a Young's Modulus is computed to be $0.5 \times 10^{10}$ Pa.

Triassic/Jurassic Sediments and Basalts: For our purposes we treated the Triassic/Jurassic sediments and included basalts (including the capping "J" horizon basalt) as one unit. Gravity modeling constrained by seismic data indicated an average density of 2.52 g/cm$^3$. This density would imply a compressional wave velocity of 4.5 km/s (Gardner et al., 1974). We assumed a Poisson's ratio of 0.31. These allowed Young's Modulus to be computed at $0.38 \times 10^{11}$ Pa. This material is found between the "B" and "J" seismic horizons in Figure 7-1.
Figure 7-2. Node map used for the two-dimensional stress model (1 of 3).
Figure 7-3. Node map used for the two-dimensional stress model (2 of 3).
Figure 7-4. Node map used for the two-dimensional stress model (3 of 3).
### Figure 7-5. Relative principal stress magnitude from the two-dimensional stress model (1 of 3).

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**Legend:**
- Coastal Plain Sediments
- Triassic/Jurassic Sediments and Basalt (Mesozoic Basins)
- Mafic Pluton (Gabbro)
- Rigid Granitic Crystalline Rock
- Viscoelastic Granitic Crystalline Rock
- Principal Stress (X10^7 Pa)

**Notes:**
- Principal Stress Axis:
  - Magnitude X10^7 Pa
  - Direction = 90° ± 12°
Figure 7-6. Relative principal stress magnitude from the two-dimensional stress model (2 of 3).
Figure 7-7. Relative principal stress magnitude from the two-dimensional stress model (3 of 3).
Figure 7-8. Relative maximum shear stress from the two-dimensional stress model (1 of 3).
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<td>MAGNITUDE X10^7 Pa</td>
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<td>66</td>
<td>DIRECTION = 45°/135° ± 12°</td>
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**LEGEND**

- **COASTAL PLAIN SEDIMENTS**
- **TRIASSIC/JURASSIC SEDIMENTS AND BASALT (MESOZOIC BASINS)**
- **MAFIC PLUTON (GABBRO)**
- **RIGID GRANITIC CRYSSTALLINE ROCK**
- **VISCOELASTIC GRANITIC CRYSSTALLINE ROCK**
- **MAXIMUM SHEAR STRESS (X10^7 Pa)**

**Figure 7-9.** Relative maximum shear stress from the two-dimensional stress model (2 of 3).
Figure 7-10. Relative maximum shear stress from the two-dimensional stress model (3 of 3).
Granitic Crystalline Rock: Below the "B" horizon we assume crystalline rock of granitic composition. Mafic intrusives and other rock types exist within the granitic rock. For modeling purposes we assume the crystalline rock to be either of granitic or mafic composition. The granitic composition rock was assigned a density of 2.67. The major mafic intrusives were considered to have a composition similar to gabbro and gravity modeling confirmed the use of a density of 2.97 g/cm$^3$ for them. The compressional wave velocities of the rocks and the elastic properties are a function of temperature and pressure. Figure 7-11 shows temperature-pressure relation for granite and gabbro. We do not know the temperature versus depth relationship appropriate for the Charleston area at seismogenic depths, but we consider the use of the curve on Figure 7-11 to be acceptable because at the depths of interest the velocity is relatively insensitive to the temperature. We have chosen compressional wave velocities of 6.15 and 6.32 km/s, respectively for granitic and gabbroic rock within the rigid crust. In both granitic and gabbroic rock, we assume a Poisson's ratio of 0.25 and compute a Young's Modulus of 0.68 x 10$^{11}$ and 0.12 x 10$^{12}$ Pa for the granitic and gabbroic rock, respectively. The very flat velocity curves between 5 and 20 km on Figure 7-11 allow us to use single modulus values for the entire thickness of the rigid crust.

Viscoelastic Crustal Rock: The base of the rigid crust varies from 10 to 23 km in depth. The crustal rock in the lower crust below the base of the rigid crust is considered to behave like a viscoelastic medium and to be granitic in composition. A density of 2.67 g/cm$^3$ and a compressional wave velocity of 6.23 km/s were assumed on the basis of the temperature-pressure relation shown on Figure 7-11; however, in order to approximate the effects of the viscoelastic medium we assigned a lower Young's Modulus and Poisson's ratio in the finite-element code.

Mantle: Mantle material is assumed to have a density of 3.07 g/cm$^3$ and a compressional wave velocity of 8.2 km/s. These values were not used in the finite element model because the target of the analysis was the rigid stress channel at mid-crustal depths which is isolated from the mantle by a viscoelastic lower crust.

7.3 Modeling Results

The results of the modeling, using the above described parameters, are indicated in Figures 7-5 through 7-10. The magnitude of the maximum principal stress axis is plotted in Figures 7-5 through 7-7. The direction of the principal stress axis is within 10 degrees of horizontal as would be expected from the application of a horizontal plate stress. The magnitude of the stress in the plate is approximately half the applied stress because the regional stress was applied to only a portion of the end of the plate and because the top of the model was not constrained. The maximum shear stress is shown in Figures 7-8 through 7-10. The maximum shear stress is
Figure 7-11. Effect of pressure and temperature on compressional velocity. (From Steinhart and Meyer, 1961; modified after Birch, 1960).
strongly controlled by the horizontal plate stress and its magnitude is thus approximately half the magnitude of the maximum principal axis. The direction of the plane of maximum shear stress will be within 12 degrees of 45 and 135 degrees from vertical.

Regional plate stresses in the crust (or horizontal ridge push stresses assumed to be applied uniformly at the southeastern boundary of the model) generate stresses within the Triassic/Jurassic basins that are half the magnitude of the stress in the granitic crystalline rock below them. The greater contrast in Young’s modulus between Coastal Plain sediments and the Triassic/Jurassic basin sediments likewise induces lower stress in the Coastal Plain sediments. The fact that Coastal Plain sediments are unconfined at the surface adds to this effect. These results suggest that Coastal Plain and Triassic sediments are effectively insulated from crustal stress.

The maximum shear stress is increased at the interface of Triassic/Jurassic rocks with the crystalline crust. The values at the top of the crystalline rock are as much as 50 percent greater than in the center of the rigid crust. This stress increase is attributed to the difference in rigidity between the two materials.

The thinning of the rigid crust to the northwest increases the maximum shear stress by as much as a factor of two above and to the southeast of the rise in the base of the rigid crust.

Two mafic plutons are included in the model of the crust. The first is 8 km wide at its base and 4 km wide at its top at a depth of 4 km. The stress in the crust above the mafic pluton is decreased in the less rigid rock above and below up to approximately 20 percent. The second pluton rests directly above the viscoelastic lower crust and is 6 km wide and has its top at a depth of 8 km with a bottom at 10 km. The pluton actually extends deeper but is is also modeled as viscoelastic below 10 km. Horizontal principal stresses in the pluton are about 20 percent higher than material just above it. The highest stresses in the model are found in this pluton. This pluton is located near the Bowman seismic zone (Figure 8-2). This decrease in the magnitude of the principal stress and maximum shear stress above and below a rigid body may be explained by the bearing of the stress by the rigid body. More extreme variations in strength or geometry will cause proportionally larger stress concentrations.

In summary, our two-dimensional stress model, based on our geologic model for the Charleston epicentral area (Figure 8-2), indicates that perturbations in crustal stress due to stress amplification or concentration can be in the order of 10 to 100 percent. The regional plate stresses are borne mainly by the rigid crystalline portion of the crust. The Triassic-Jurassic basins and Coastal Plain sediments are effectively insulated
from the crustal stress; as a result, there is an amplification of stress in the upper portion of the rigid crystalline crust. There is also a stress amplification of about 20% within the mafic plutons, and a corresponding decrease in stress in the crystalline crust above and below them. Finally, the thinning of the crystalline rigid crust to the northwest of Charleston greatly increases the crustal stress, but also limits the thickness of rigid crust available for faulting, hence limiting the size of the maximum possible earthquakes.


# APPENDIX A

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ABSTRACT

The object of this report is to present data relevant to the Charleston Earthquake in a single appropriate format. All data are referenced to equally spaced points on the Universal Transverse Mercator projection, zone 17. Values at each point are weighted averages of surrounding points within a restricted radius of two grid increments. Duplicate or inconsistent data points were removed from the gravity data and the precision was estimated for each grid point.

About 600 new gravity observations were obtained in areas of sparse coverage near the epicenter of the 1886 Charleston earthquake. These new values increased the existing gravity data set by 20 percent from 3150 to 3750 points in a 128 by 128 km rectangular area centered on the epicenter of the Charleston earthquake. Most of the new gravity values were obtained at 0.5 km increments along lines.

The four data grids defined herein are centered about the epicentral zone of the 1886 Charleston earthquake. They are squares in the Universal Transverse Mercator projection and are rotated clockwise 52 degrees about the point (33.125°N, 81.25°W), which corresponds to the point (1,1) in the 128x128 point grid with a 1.0 km spacing. The other grids are centered on this grid exactly and have sides of 256 points at 4.0 km spacing, 128 points at 8.0 km spacing and 4096 points at 31.25 m spacing.
1. DOCUMENTATION OF CHARLESTON AREA DATA SETS AND COMPUTER PROGRAMS

Introduction

Most studies, which have analyzed geophysical data covering the epicentral zone of the 1886 Charleston earthquake, have presented the data in a format that is convenient for analysis and provides the best display. But, different data types, such as landsat images, gravity data, magnetic data, and magnetotelluric soundings are best presented and most conveniently analyzed in different and often incompatible formats. Hence, the first objective of this study of data relevant to the Charleston earthquake was to establish a single appropriate format for all data. The format would permit the direct comparison of a variety of data types and the use of analysis techniques for multiple data sets on a common data base. The second objective was to collect the existing data and to adjust the data to be compatible with the common data base. In most cases this requires a change in format and a merging of multiple data sets from different sources. A third objective was to provide a mechanism to update the data when new data become available and to assess the accuracy of the data. The forth objective was to present the collected data in a format appropriate for distribution.

Definition of Grids

The use of a two-dimensional planar representation of data on an ellipsoidal surface is inherently non-conformable. The distortion of distances, directions and areas will depend on the projection. A variety of projections (including Lambert conic, Universal Transverse Mercator, and Albers equal area) have been used for the data available to this study. A direct comparison of data on different projections can be difficult since equally distant grid points in each projection may not represent the same point on the earth's surface. In order to compare data which were originally in different projections, all the data need to be referenced to a grid in the same projection. The landsat data are conventionally displayed using the Universal Transverse Mercator projection. Because the landsat images contain the greatest number of points, the computational effort required to effect conversion among projections would present the greatest difficulty. For this reason we have chosen the Universal Transverse Mercator projection (zone 17) to map latitude and longitude to a plane surface on which a uniform rectangular grid can be defined. Other projections, for example the Albers Equal Area Conic projection, are more common and more appropriate for large study areas such as the eastern United States. However, the largest area of interest in this study has a longitudinal dimension of about 1500 km and the distortion at this distance related to the Universal Transverse Mercator (UTM) projection is significantly less than the precision necessary for the data presented in the large grid. The area of the largest grid extends beyond zone 17, but for coordinates outside zone 17 the zone is fixed at 17 for consistency. FORTRAN sub
routines UTMLL and LLUTM for converting UTM coordinates to latitude and longitude and back are given in Appendix A-6.

The Gridding Program

The interpolation of data to a rectangular grid was accomplished by a weighted average. The weighted average was limited to a defined small area in order to allow the grid to be easily updated any time new data are available. Also, the computational implementation of the weighted average is efficient and stable.

Values at each grid point were determined by the weighted average of all data points falling within an area defined by a square with four grid points on a side (figure A-1-1). The weights are a function of distance and decrease with increasing distance between the grid point and the data point. The data points are transformed from their original coordinate system to the Universal Transverse Mercator projection. After the grid area surrounding a data point is identified, the surrounding 16 grid points are found. For each grid point the distance to the data point is computed. Then a normalized weight function is calculated by Equation 1.

\[ W_i = W_i / \sum_{i=1}^{16} W_i \]  

where:

- \( W_i = [1/(1+(r_i/dx)^2)] \), the weight function
- \( dx = \) grid point separation
- \( r_i = \) distance from data point to grid point

By normalizing the weights, they are equivalent to the number of points contributing to a grid point or the density of data for the area represented by one grid point. With this distance dependent weight, appropriately greater weight is given to the points closer to the grid points. Since data points near the edge of the grid area do not have 16 surrounding grid points, two extra rows (or columns) were added at the four edges of the grid for convenience in programming. These values are preserved for the addition of new data to the grid but are excluded from the grids used in analysis. The FORTRAN program SNGGRID used to generate the grid is given in Appendix A-6.

The gridding technique employed in program SNGGRID works best when the data density is uniform and similar to the density of the grid. In areas where the data are more dense, an averaged and smoothed value is given at the grid point, simulating the average effect of the field surrounding the grid point and not just the value at the grid point. The average is preferable to a point value for modeling since it better
Figure A-1-1. Relation between area of occurrence of values and the grid points affected.
represents the block corresponding to the grid point. In areas of high data density, the gridded data represent a smoothing of the original data within a radius equivalent to the grid spacing. For the more difficult condition of areas which lack data, the gridding technique yields 4 by 4 squares of constant value or grid points with zero value. For these conditions, a program to expand the radius of smoothing was developed. This FORTRAN program, AB, considers each point at which the weight (equivalent number of points) falls below a threshold value determined by the criterion that less than three points contributed to the value. For those points, the area of averaging was expanded until the equivalent of six points contributed to the value and the weighted average was computed. This is equivalent to choosing a larger grid increment and interpolating between grid points. The sparse areas that would be affected the greatest are along the coast or over lakes or swamps outside the Charleston epicenter area. In these areas, the average value is more appropriate than an extrapolated value, because of the extreme values that extrapolated values can obtain when unconstrained on one side.

Sources of Gravity Data

The gravity values on the 1 km 128x128 point grid (see A-3 for definition of grids) were interpolated directly from available gravity observations. The elevation values for the 1 km grid were interpolated from the elevations of the gravity data. Because approximately 600 new gravity observations (described in A-2) were obtained during this project, and additional data have been obtained in the last few years, special care was taken to assure that this data set would be internally consistent. All the data were converted, if necessary, to the IGSN 1971 datum (International Association of Geodesy, 1971b) and anomalies were calculated using the 1967 Geodetic Reference System (International Association of Geodesy, 1971a).

The data from Champion (1975) consist of approximately 2000 observations, 1000 of which are along 11 detailed profiles. The data spacing along the profiles was 0.5 km. The remaining 1000 measurements are regional data having an average station spacing of 1.0 km. LaCosta-Romberg meters were used exclusively and the combined uncertainty in drift and reading precision was 0.15 mGal for the line data. The elevation control limited the precision of the regional data to 0.2 mGal. The Champion (1975) data were obtained in an area defined by the corner locations (32° 37.5' N, 80° W) and (33° 7.5' N, 80° 22.5' W). This area includes a major portion of the epicentral zone of the 1886 earthquake as well as the epicenters of the more recent seismic events.

Gravity data from McKee (1973) cover the region of the February 3, 1972, Bowman, South Carolina, earthquake. Excluding base stations, 344 gravity readings were obtained. The data include one line at 0.5 km spacing and regional data at about 1.0 km spacing in a 400 km² area.
During September, 1981, Georgia Tech was commissioned by the Southeastern Exploration and Production Company to obtain proprietary data in the area of Bamberg, South Carolina. The time limit on the proprietary status expired in 1985. These data consist of 89 observations along two lines. The data spacing was 0.5 km on one line and 1.0 on the other.

The 549 regional gravity measurements obtained from the U. S. Geological Survey (Phillips and Davis, 1985) were collected in July, 1977 and June, 1978, as part of on-going geophysical investigations in the vicinity of the epicenter of the 1886 Charleston earthquake. An additional 95 gravity measurements were collected at 500 foot intervals along a southwest trending line crossing the Ashley river.

A data set containing regional data was obtained from the Defense Mapping Agency (DMA). These data are at a spacing of 5 to 15 km. The precision of the older data in this data set is uncertain. The DMA data also contain more recent regional data from Virginia Polytechnic Institute, which are comparable in precision with other recent data.

The Georgia Tech gravity data library also contains gravity data obtained by Woollard during the 1950's. These data predate a national base network and were tied to pendulum data. A bias in the pendulum data introduced a datum shift equivalent of 2 to 4 mGal depending on the location. The Woollard data were not used because most of the stations have subsequently been reoccupied. Also, recent data obtained by the University of South Carolina were not made available, and therefore are not included in the data set. The recent University of South Carolina data cover the northern corner of the 1 km grid.

The marine gravity data available offshore South Carolina are either outside or at the very southeastern edge of the 128 by 128, 1 km grid. Only a few points could contribute to the gravity values. Because there exists a gap of 5 to 10 km between the onshore data and the offshore data and because the contribution of the offshore data would be intermittent and uneven on the edge of the grid, these offshore data were not included in the 128 by 128, 1 km grid.

The magnetic data for the 1.0 km grid were obtained from the US Geological Survey, from a digitization and merging of recent aeromagnetic surveys. (Jeff Phillips, personal communications). The digitized magnetic data from the U. S. Geological Survey were on a Transverse Mercator projection at 0.5 km intervals. These coordinates were converted to the rotated Transverse Mercator projection and gridded at a 1 km interval.

The starting data sets for the 4.0 km and 8.0 km spaced grids were the Electric Power Research Institute (EPRI) magnetic, Bouguer gravity and elevation data grids. These are spaced at 4.0 km increments in the north and east direction using an Albers Equal Area Conic projection with two standard parallels, 29.5° and 45.5°, and origin at the equator and 96° west longitude. The Albers Equal Area Conic projection was converted to our rotated Transverse Mercator projection and gridded at
4.0 and 8.0 km intervals. The data were provided on magnetic tape courtesy of EPRI.

The bathymetry data for areas off-shore were obtained from the National Geophysical Data Center, NOAA, E/GC in the 5 by 5 minute grid-ded data format. These were used to fill in areas of the EPRI data over the ocean that were lacking in bathymetric data.

Merging and Compiling Data

All the data incorporated in the 1 km grid for gravity data were carefully examined. Duplicate points and points which were inconsistent with neighboring points were removed before generating the grid. The program designed to remove duplicate points "CLEAN" and the program designed to identify inconsistent data "CLERR" are given in Appendix A-6.

Program CLEAN was designed to identify duplicate and virtual duplicate points. Each new point was compared to a sorted listing of the gravity points and those pairs that were closer than a distance of 0.2 km were listed for examination. One of the duplicate points was then removed. The choice of which point to remove was based on the value of the Bouguer Anomaly. Duplicate points were common because the same data were often obtained from multiple sources. This duplicity was easily identified on the basis of identical gravity values and survey designations. In a few cases the same data were reduced using two different international gravity formulae. The standard differences in the absolute value of gravity allowed a choice of the data referenced to the IGSN 71 datum. When the same location was sampled by two different surveys, the choice of which value to use was more difficult. In general, we chose the value most consistent with neighboring points. In some surveys, data were obtained at closely spaced intervals along lines. Such data tend to bias values computed by a weighted average technique by concentrating excessive weight at a few grid points along these lines. In order to minimize this kind of bias and provide a data set with more uniform data distribution, selected data points were removed from these lines. In essence, points closer than 0.2 km were considered duplicates and selectively removed.

Program CLERR was designed to identify values that were anomalous or inconsistent. Each point tested was removed from the data set and the eight nearest points were found. These points were then used to estimate by a weighted average method the value and uncertainty at the point. Any point that exceeded one standard deviation of the uncertainty of the extrapolated value was considered to be a possible error or inconsistent value. These values were examined for a possible correction. If a correction was not possible and the apparent error could not be explained by gradients or uncertainty in the data, the value was considered in error and removed.
Assessment of Precision

The weighted average method used in gridding the gravity data is easily adaptable to computation of precision. The equations in Heiskanen and Moritz (1968, pg 267) were used. The relation requires the autocorrelation function of the gravity data in order to incorporate the variation of gravity data with distance in the estimate of precision of extrapolated data. The equation used to compute $m_p^2$, the variance at a point $p$, was

$$m_p^2 = m^2 + C_0 - \sum_{i=1}^{n} \alpha_{pi}^2 C_{pi} + \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{pi} \alpha_{pk} C_{ik}$$  \hspace{1cm} (2)

where $m^2$ is the variance of the data measurement,

$\alpha_{pi}$ is the normalized weight for the point $p$ to the gravity value at $i$

$C_{ik}$ is the covariance function at a distance equal to the separation of the $i$th and $k$th points.

$n$ is the number of data points in the average.

The autocorrelation function for the gravity data in the Charleston 128 by 128, 1 km grid are shown in figure A-1-2. The correlation distance is 15 km and the variance is 80 mGal$^2$ (+ 9 mGal standard deviation). Using this autocorrelation function and the distribution of gravity data, the estimated error at any point can be computed.

Presentation of the Data

A summary of the data grids and computer programs which have been generated is given in table I. The Bouguer gravity anomalies, elevations, and their weights for the 128 by 128, 1 km grid are combined in file GRIDRAW. The weights are identical for the elevations and Bouguer gravity anomalies. The elevations were obtained directly from the gravity data and, thus, if desired, the free air anomalies could be computed from the Bouguer anomalies and elevation data. The Bouguer anomalies are in milligals, the elevation in feet and the weights in data points per square kilometers. The smoothed and extrapolated Bouguer anomalies and elevations, obtained by applying program AB to file GRIDRAW are combined with the magnetic data in file GD1SMT. The precision of the file is limited to 0.1 mGal, .1 ft., and 1.0 gamma. GD1SMT has also been separated for convenience and use on microcomputers into separate files for Bouguer anomalies (GD1SMTG), elevations (GD1SMTE) and magnetic anomalies (GD1SMTM). The contoured versions of these data are shown as figures A-1-3, 4, and 5, respectively.

The 64 by 64, 4 km grid and the 128 by 128, 8 km grid data were obtained largely from the EPRI 4 km grid data. The Bouguer gravity anomalies, elevations and magnetic anomalies are contained in GD2RAW and GD3RAW for the 4 km and 8 km grids, respectively. As with the 1 km
grid, separate files are available for the Bouguer anomalies, elevations and magnetic anomalies. These are presented as figures A-1-6,7, and 8, respectively, for the 4 km grid and as figures A-1-9, 10, and 11, respectively, for the 8 km grid. The Bouguer anomalies in figure A-1-6 and 9 have been corrected for bathymetry over the ocean and hence appear negative off the continental shelf in GD3RAWG. However, the areas of coverage of GD2RAWG is on the continental shelf in shallow water and is not affected significantly by the depth of the water. The elevation data from EPRI did not indicate bathymetry data over the oceans. The ocean elevations were all given as zero. In GD3RAWE and GD3RAWE we have supplemented and replaced the EPRI sea surface values with bathymetry. The magnetic data from EPRI contain two areas with no data. At this time these two areas, which are over the ocean and at the edge of the grid, have been left open until compatible data are found.

Table I. Names of Programs and Data Grids for the Charleston Area.

<table>
<thead>
<tr>
<th>Filename</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRIDDRAW</td>
<td>Unsmoothed gravity anomalies, elevations and weights in Freefield format. Full precision is preserved for addition of new data.</td>
</tr>
<tr>
<td>GD1SMT</td>
<td>Smoothed Bouguer anomalies, elevations, and magnetic anomalies with limited precision. Format is 24I5 in groups of 132. The grid is 132 by 132 and includes the buffer.</td>
</tr>
<tr>
<td>GD1SMTG</td>
<td>Bouguer Anomalies from GD1SMT. Format is 24I5 in groups of 132. Units are tenths of mGals.</td>
</tr>
<tr>
<td>GD1SMTE</td>
<td>Elevations from GD1SMT. Units are tenths of feet. Format is 24I5 in groups of 132.</td>
</tr>
<tr>
<td>GD1SMTEG</td>
<td>Magnetic anomalies from GD1SMT.</td>
</tr>
<tr>
<td>GD2RAW</td>
<td>Bouguer Gravity, elevations and magnetic anomalies in the 4 km grid. Format is 10F8.1 continuous for the remaining grids (i.e. BOUG(I,J),ELEV(I,J),MAG(I,J), I=1,68,J=1,68)</td>
</tr>
<tr>
<td>GD2RAWG</td>
<td>Bouguer anomalies in 4 km grid.</td>
</tr>
<tr>
<td>GD2RAWE</td>
<td>Elevations in 4 km grid.</td>
</tr>
<tr>
<td>GD2RAWM</td>
<td>Magnetic anomalies in 4 km grid.</td>
</tr>
<tr>
<td>GD3RAW</td>
<td>Bouguer anomalies, elevations and magnetic anomalies in the 8 km grid. Format is 10F8.1 continuous. (i.e. BOUG(I,J),ELEV(I,J),MAG(I,J), I=1,132, J=1,132)</td>
</tr>
<tr>
<td>GD3RAWG</td>
<td>Bouguer anomalies in 8 km grid.</td>
</tr>
<tr>
<td>GD3RAWE</td>
<td>Elevations in 8 km grid.</td>
</tr>
<tr>
<td>GD3RAWM</td>
<td>Magnetic anomalies in 8 km grid.</td>
</tr>
<tr>
<td>ANSEPS3</td>
<td>Unsorted and uncleaned gravity data for 1 km grid. DoD gravity data format.</td>
</tr>
<tr>
<td>ANSEPS4</td>
<td>Sorted and cleaned gravity data for 1 km grid. DoD gravity data format.</td>
</tr>
<tr>
<td>SCDATA</td>
<td>Listing of new Charleston area data (1985-86).</td>
</tr>
</tbody>
</table>
Figure A-1-2. One dimensional approximation for the autocorrelation function of the Charleston area gravity data.
Figure A-1-3. Contour plot of smoothed Bouguer anomalies in GD1SMTG. Data are from the 128 x 128 point grid with a 1.0 km grid interval. Contour interval is 2 mGal.
Figure A-1-4. Contour plot of smoothed elevations in GD1SYTE. Data are from the 128 x 128 point grid with a 1.0 km grid interval. Contour interval is 20 feet.
Figure A-1-5. Contour plot of smoothed weights in GD1SMTH. Data are from the 128 x 128 point grid with a 1.0 km grid interval. Contour interval is 1.0 point per square km.
Figure A-1-6. Contour plot of smoothed magnetic anomalies in GD1SMTM. Data are from the 128 x 128 point grid with a 1.0 km grid interval. Contour interval is 100 gammas.
Figure A-1-7. Contour plot of Bouguer anomalies in GD2RANG. Data are from the 64 x 64 point grid with a 4.0 km grid interval. Contour interval is 5.0 mGal.
Figure A-1-8. Contour plot of elevations in GD2RAWE. Data are from the 64 x 64 point grid with a 4.0 km grid interval. Contour interval is 10 meters.
Figure A-1-9. Contour plot of magnetic anomalies in GD2RAWM. Data are from the 64 x 64 point grid with a 4.0 km grid interval. Contour interval is 125 gammas.
Figure A-1-10. Contour plot of Bouguer gravity anomalies in GD3RAWG. Data are from the 128 x 128 point grid with an 8.0 km grid interval. Contour interval is 10 mGal.
Figure A-1-11. Contour plot of elevation in GD3RAWE. Data are from the 128 x 128 point grid with an 8.0 km grid interval. The contour interval is 250 feet.
Figure A-1-12. Contour plot of magnetic anomalies in GD3RAWE. Data are from the 128 x 128 point grid with an 8.0 km grid interval. The contour interval is 100 gammas.
2. **PRINCIPAL FACTS FOR NEW CHARLESTON AREA GRAVITY DATA**

**Introduction**

An investigation and evaluation of the causes of seismicity near Charleston, South Carolina, may be optimized by an examination of available data in a uniform format. The Bouguer gravity anomalies will provide valuable constraints for determination of the structures in the crust. An objective of gravity data acquisition and analysis is to accumulate available gravity data for the Charleston vicinity and to increase the density of coverage, where appropriate, in a 128 by 128 km rectangular area centered on the epicentral zone of the 1886 Charleston earthquake. In this report, the principal facts are documented for new gravity data obtained within the 128 x 128 km area. Other reports will document the design of data grids, and the modeling of the crust using gravity and magnetic data.

The goal in gravity data acquisition was to provide sufficient data to complete a grid with a uniform 1.0 km spacing between points and 128 points on each side. The grid is to be rotated to follow the coastline and maximize the land area. Such a grid would require 16,000 points and only about 3200 points were available prior to this study. Since resources were available for only about 600 new data points, the locations of the 600 points were concentrated in areas of sparse coverage near the epicenter of the 1886 Charleston earthquake. Hence, areas of new data were chosen to expand the areas of existing coverage in the central portion of the grid and to fill in large areas without coverage.

**Sources of Data:**

The largest single block of data was obtained by Champion (1976). The Champion (1976) data (shaded central block in figure 1) include detailed survey areas near the epicenter of the 1886 earthquake. Gravity data in the area of the 1972 Bowman earthquake were obtained by McKee (1976). Other Georgia Tech data include a selection of detailed line data and existing regional data. U.S. Geological Survey data (Phillips and Davis, 1985) were made available to the study. These data expand the Champion (1976) data to the west, northwest, and north. Data from the Virginia Polytechnic Institute and State University and other data available from the DoD Gravity Services Branch complement the U.S. Geological Survey data. University of South Carolina data (not made available to this study) cover the northern corner of the study area. Consequently, based on this existing coverage, it was decided to obtain additional data east of the Champion (1976) data and to fill in major holes between the U.S. Geological Survey and Bowman area data. The only remaining significant areas of sparse data would be in areas of difficult access near the coast and lake or swamp areas to the north.
Figure A-2-1. Areas of gravity data coverage prior to the Georgia Tech field survey.
Standard methods of data acquisition and reduction were followed. Data reduction utilized program "GRAVUN" on file at the Georgia Institute of Technology, School of Geophysical Sciences. Corrections were applied for earth tides and drift. Observed gravity values are referenced to the IGSN 1971 datum (International Association of Geodesy, 1971b) and anomalies were calculated using the 1967 Geodetic Reference System (International Association of Geodesy, 1971a). No terrain corrections were applied because of the gentle topography. Data were obtained along lines at a spacing of less than 0.5 km or as regional data at a 1.0 km spacing. These techniques are outlined in Champion, 1976. Table A-2-1 lists the surveys. All surveys were made with LaCoste-Romberg gravity meter number 668. All data are tied to the Branchville state base. Temporary base station values are given in Table A-2-2. Figure 2 is a point plot of the new data obtained and figures 3a-f are point plots of the total composite gravity data coverage, except for the University of South Carolina data which were not made available. Table A-2-3 is a listing of the new gravity data in standard DoD format (figure A-2-4).

Table A-2-1. List of surveys and principal facts.

<table>
<thead>
<tr>
<th>Survey Number</th>
<th>Data Time</th>
<th>Quad Sheet(s)</th>
<th>Operator</th>
<th>Type Base No. Drift Sta. mGal/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>909</td>
<td>9/07/85 8:56-12:14 Summerville NW</td>
<td>Alexander Line StJ</td>
<td>41</td>
<td>0.09</td>
</tr>
<tr>
<td>910</td>
<td>9/08/85 9:30-12:56 Summerville NW</td>
<td>Alexander Line EXX</td>
<td>45</td>
<td>0.14</td>
</tr>
<tr>
<td>911</td>
<td>9/09/85 8:50-13:45 Pringletown</td>
<td>Alexander Line BST</td>
<td>46</td>
<td>0.16</td>
</tr>
<tr>
<td>912</td>
<td>9/13/85 10:35-18:28 Kittridge</td>
<td>Alexander Line Dup</td>
<td>62</td>
<td>0.12</td>
</tr>
<tr>
<td>913</td>
<td>9/15/85 12:00-15:57 Kittridge</td>
<td>Alexander Line TAV</td>
<td>32</td>
<td>-0.01</td>
</tr>
<tr>
<td>914</td>
<td>9/16/85 8:29-13:08 Maple Cane Sw.</td>
<td>Alexander Line S18</td>
<td>71</td>
<td>0.13</td>
</tr>
<tr>
<td>915</td>
<td>9/24/85 12:12-16:34 Kittridge</td>
<td>Alexander Line I41</td>
<td>52</td>
<td>0.09</td>
</tr>
<tr>
<td>916</td>
<td>9/25/85 11:11-14:14 Huger</td>
<td>Alexander Line I41</td>
<td>35</td>
<td>0.07</td>
</tr>
<tr>
<td>917</td>
<td>9/26/85 10:15-14:16 Huger</td>
<td>Alexander Line I41</td>
<td>54</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>18:24-19:36</td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>918</td>
<td>9/27/85 11:13-15:07 Maple Cane Sw.</td>
<td>Alexander Line 161</td>
<td>48</td>
<td>0.09</td>
</tr>
<tr>
<td>919</td>
<td>9/23/85 12:22-16:49 Base Stations</td>
<td>Alexander</td>
<td>reg. Kylie</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Base station loop &quot;Branchville state base-Wylie-StJ-Tav-EXX-BST-518-Branchville State Base&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>920</td>
<td>6/06/86 11:50-17:54 Base Stations</td>
<td>Alexander</td>
<td>reg. Kylie</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Base station loop &quot;Wylie-Dup-TAV-I41-Wylie&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>922</td>
<td>6/06/86 11:50-17:54 St. George SW</td>
<td>Radford</td>
<td>reg. ESB</td>
<td>28</td>
</tr>
<tr>
<td>923</td>
<td>6/07/86 9:24-13:35 Reevesville</td>
<td>Radford</td>
<td>reg. ESB</td>
<td>49</td>
</tr>
</tbody>
</table>

A-2-3
### Table A-2-1 (cont.)

**Base Station Abbreviations**

- BSB Branchville State Base
- TAV Tavou Church
- I41 Highway 41 at S-8-98
- Dup Dupont plant entrance

### Table II. Gravity values at temporary base stations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Surveys</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elev.(m)</th>
<th>Value (mgals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branchville</td>
<td>922,923</td>
<td>33 .15</td>
<td>80 49.00</td>
<td>38.6</td>
<td>979577.051</td>
</tr>
<tr>
<td>Kylie</td>
<td>920,919</td>
<td>33 .97</td>
<td>80 11.67</td>
<td>25.0</td>
<td>979557.292</td>
</tr>
<tr>
<td>Dupont</td>
<td>912</td>
<td>33 3.14</td>
<td>79 57.00</td>
<td>3.9</td>
<td>979567.737</td>
</tr>
<tr>
<td>TAV</td>
<td>913</td>
<td>33 6.35</td>
<td>79 56.42</td>
<td>9.1</td>
<td>979569.350</td>
</tr>
<tr>
<td>I41</td>
<td>915,16,17</td>
<td>33 5.76</td>
<td>79 48.29</td>
<td>7.9</td>
<td>979567.575</td>
</tr>
<tr>
<td>StJ</td>
<td>909</td>
<td>33 8.37</td>
<td>80 9.69</td>
<td>20.1</td>
<td>979567.896</td>
</tr>
<tr>
<td>EXX</td>
<td>910</td>
<td>33 8.53</td>
<td>80 9.66</td>
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<td>979568.270</td>
</tr>
<tr>
<td>BST</td>
<td>911</td>
<td>33 12:50</td>
<td>80 15.43</td>
<td>25.9</td>
<td>979578.955</td>
</tr>
<tr>
<td>S18</td>
<td>914</td>
<td>33 1.53</td>
<td>80 23.22</td>
<td>19.2</td>
<td>979561.509</td>
</tr>
<tr>
<td>S61</td>
<td>918</td>
<td>33 3.06</td>
<td>80 29.99</td>
<td>18.9</td>
<td>979561.375</td>
</tr>
</tbody>
</table>
Figure A-2-2. Point plot of new data obtained by Georgia Tech.
Figure A-2-3a. Point pot of gravity data in the degree square 33°N, 80°W.
Figure A-2-3b. Point plot of gravity data in the degree square $33^\circ N, 81^\circ W$. 

A-2-7
Figure A-2-3c. Point plot of gravity data in the degree square $32^\circ$N, $81^\circ$W.
Figure A-2-3d. Point plot of gravity data in the degree square 32°N, 80°W.
Figure A-2-3e. Point plot of gravity data in the degree square 33°N, 79°W.
Figure A-2-3f. Point plot of gravity data in the degree square 32°N, 79°W.
Table A-2-3. Listing of new Charleston data in DoD format.

| 33 853 | 80 966 1 | 201 | 3568245- | 264- | 489 | G909 SC 0 | 2 | 0 |
| 33 870 | 80 998 1 | 192 | 3568422- | 299- | 513 | G909 SC 0 | 3 | 3 |
| 33 886 | 80 1028 1 | 152 | 3570750- | 210- | 380 | G909 SC 0 | 4 | 3 |
| 33 904 | 80 1053 1 | 128 | 3571073- | 278- | 421 | G909 SC 0 | 5 | 2 |
| 33 930 | 80 1068 1 | 207 | 3570112- | 165- | 396 | G909 SC 0 | 6 | 2 |
| 33 956 | 80 1076 1 | 183 | 3571099- | 178- | 382 | G909 SC 0 | 7 | 3 |
| 33 965 | 80 1068 1 | 168 | 3571325- | 242- | 429 | G909 SC 0 | 8 | 3 |
| 331018 | 80 1061 1 | 183 | 3571608- | 212- | 416 | G909 SC 0 | 9 | 3 |
| 331049 | 80 1061 1 | 192 | 3571723- | 215- | 429 | G909 SC 0 | 10 | 3 |
| 331071 | 80 1065 1 | 122 | 3574042- | 261- | 397 | G909 SC 0 | 12 | 2 |
| 331121 | 80 1035 1 | 189 | 3573248- | 171- | 382 | G909 SC 0 | 13 | 3 |
| 331148 | 80 1026 1 | 195 | 3573890- | 127- | 344 | G909 SC 0 | 14 | 2 |
| 331172 | 80 1013 1 | 183 | 3576578- | 222- | 426 | G909 SC 0 | 17 | 3 |
| 331207 | 80 1013 1 | 186 | 3577088- | 3- | 210 | G909 SC 0 | 18 | 3 |
| 331277 | 80 1024 1 | 168 | 3578004- | 23- | 164 | G909 SC 0 | 19 | 3 |
| 331319 | 80 1037 1 | 152 | 3579638- | 81- | 382 | G909 SC 0 | 20 | 3 |
| 331350 | 80 1014 1 | 189 | 3574489- | 23- | 178 | G909 SC 0 | 33 | 3 |
| 331385 | 80 1014 1 | 192 | 3575518- | 54- | 254 | G909 SC 0 | 16 | 2 |
| 331385 | 80 1014 1 | 183 | 3576578- | 222- | 426 | G909 SC 0 | 17 | 3 |
| 331370 | 80 1013 1 | 186 | 3577088- | 3- | 210 | G909 SC 0 | 18 | 3 |
| 331377 | 80 1024 1 | 168 | 3578004- | 23- | 164 | G909 SC 0 | 19 | 3 |
| 331319 | 80 1037 1 | 152 | 3579638- | 81- | 382 | G909 SC 0 | 20 | 3 |
| 331350 | 80 1014 1 | 189 | 3574489- | 23- | 178 | G909 SC 0 | 33 | 3 |
| 331385 | 80 1014 1 | 192 | 3575518- | 54- | 254 | G909 SC 0 | 16 | 2 |
| 331385 | 80 1014 1 | 183 | 3576578- | 222- | 426 | G909 SC 0 | 17 | 3 |
| 331370 | 80 1013 1 | 186 | 3577088- | 3- | 210 | G909 SC 0 | 18 | 3 |
| 331377 | 80 1024 1 | 168 | 3578004- | 23- | 164 | G909 SC 0 | 19 | 3 |
| 331319 | 80 1037 1 | 152 | 3579638- | 81- | 382 | G909 SC 0 | 20 | 3 |
| 331350 | 80 1014 1 | 189 | 3574489- | 23- | 178 | G909 SC 0 | 33 | 3 |
| 331385 | 80 1014 1 | 192 | 3575518- | 54- | 254 | G909 SC 0 | 16 | 2 |
| 331385 | 80 1014 1 | 183 | 3576578- | 222- | 426 | G909 SC 0 | 17 | 3 |
| 331370 | 80 1013 1 | 186 | 3577088- | 3- | 210 | G909 SC 0 | 18 | 3 |
| 331377 | 80 1024 1 | 168 | 3578004- | 23- | 164 | G909 SC 0 | 19 | 3 |
| 331319 | 80 1037 1 | 152 | 3579638- | 81- | 382 | G909 SC 0 | 20 | 3 |
| 331350 | 80 1014 1 | 189 | 3574489- | 23- | 178 | G909 SC 0 | 33 | 3 |
3. DEFINITION OF DATA GRIDS FOR CHARLESTON STUDY

Introduction

A major objective of the Nuclear Regulatory Commission Charleston study is to collect and examine sets of data on a common geographic reference base. In this way the various data sets can be uniformly evaluated for completeness and density of information content. The data sets can then be used to assess the hypotheses that have been proposed to explain the Charleston event and to either identify the best hypothesis or to develop a new verifiable explanation. Four grids are chosen to be compatible with available data and the relative resolution of different types of data.

Map Projection and Reference Location

The Universal Transverse Mercator (UTM) Projection (Zone 17) is used to project the latitudes and longitudes to a plane surface on which a uniform rectangular grid can be defined. The choice of the Universal Transverse Mercator Projection is based on the common use of this system for referencing landsat data. FORTRAN subroutines for converting UTM (Zone 17) to latitude and longitude and back are given in Appendix A-6. The reference grid is a 128x128 point grid approximately centered on the aftershock zone of the 1886 Charleston earthquake. The origin and orientation of this grid are chosen to provide the minimum data over the ocean, provide the best Landsat image coverage and to parallel the regional structure. The 1.0 km grid reference point (1,1) is fixed at the point (33.125°N, 81.25°W) and this point is defined as the origin in this study. The reference axis and grid are rotated clockwise about this point 52 degrees. The relationship between the UTM projection and the rotated system is shown in figure A-3-1.

The locations in the rotated system are found by the following steps:

1) transform geographic coordinates to UTM zone 17.
2) shift origin to grid point (1,1) at (N_o, E_o)
3) rotate axes clockwise 52 degrees to primed coordinate system.
4) find index of grid point closest to the data point

Computer programs to transform geographic coordinates to UTM zone 17 are included in Appendix I. The equations for step two, the translation, and step three, the rotation, may be combined as follows:

\[
E' = (E-E_o)\cos(A) - (N-N_o)\sin(A)
\]

\[
N' = (E-E_o)\sin(A) + (N-N_o)\cos(A)
\]

where A is positive clockwise.

The new primed axes (N', E') represent a clockwise rotation of the old axes (N, E) about (N_o, E_o).
Origin
Latitude = 33.125
Longitude = -81.250
N° = 3664980.84
E° = 476678.49

Figure A-3-1. Relative location of rotated reference axis of grid.

Figure A-3-2. Location of grid point relative to sample area.
Grid Definitions

Within each grid, a grid point represents data in a rectangular area centered over the grid point and with sides equal to the grid spacing. Figure A-3-2 shows the relation of the area to the grid point.

Four grids are defined. Three are located by centering them on the reference grid. Table I gives the dimensions of the grids and the coordinates of the four corner points of each grid. The relative locations of the grid points in each of the four grids are shown in figure A-3-3.

The 64x64 point grid with dimensions of 256 km is centered on the reference grid. In the primed or rotated system, the grid reference point (1,1) for the 64x64 point grid is located at $N' = -52.5$ km and $E' = -62.5$ km.

The 128x128 point grid with 8 km grid interval and dimensions of 1024 km is also centered on the reference grid. In the primed system, the grid reference point (1,1) for the 128x128 point 8 km grid is located at $N' = -444.5$ km and $E' = -444.5$ km.

The landsat data have 4096x4096 points which can be divided into 64-512x512 point units for convenient display. Each unit of 512x512 points will cover an area of side length 16 km or an area of 256 square km. The pixels are rectified to the 128x128 point 1.0 km grid points such that each 1.0 km grid point will be surrounded by four areas of 16x16 pixels. The pixels are 31.25 meters apart and the origin is at the point $N' = -484.375$ m, $E' = -484.375$ m.

The index $(IX, IY)$ of the grid points closest to a specified latitude and longitude coordinate (or UTM coordinate position) can be obtained from the following equations:

$$IX = 1 + \text{Int}[\frac{(E' - R(I) + DX(I)/2.0)}{DX(I)}]$$
$$IY = 1 + \text{Int}[\frac{(N' - R(I) + DY(I)/2.0)}{DY(I)}]$$

$(\text{Int}[] \text{ truncates fractional part of number})$

Where $R(I)$ is the origin in the primed system of the $I$th grid, $DX$ or $DY$ is the grid point spacing of the $I$th grid and in this study $DX(I) = DY(I)$.

Table A-3-Ia Size of the four grids.

<table>
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<tr>
<th>Grid No.</th>
<th>Pts/side</th>
<th>length(km)</th>
<th>grid interval</th>
<th>data</th>
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<tr>
<td>1</td>
<td>128</td>
<td>128</td>
<td>1.0 km</td>
<td>grav., mag., elev.</td>
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<tr>
<td>2</td>
<td>64</td>
<td>256</td>
<td>4.0 km</td>
<td>grav., mag., elev.</td>
</tr>
<tr>
<td>3</td>
<td>128</td>
<td>1024</td>
<td>8.0 km</td>
<td>elev., mag.</td>
</tr>
<tr>
<td>4</td>
<td>4096</td>
<td>128</td>
<td>0.03125</td>
<td>landsat,</td>
</tr>
</tbody>
</table>

A-3-3
### Table A-3-Ib Coordinates of corners of grids.

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<th>N</th>
<th>E</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>32.2211</td>
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<tr>
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<td></td>
<td>3,743,170</td>
<td>576,756</td>
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<td>80.1705</td>
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<tr>
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<td>128</td>
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<td>654,945</td>
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<th>E</th>
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<th>Longitude</th>
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<td>1</td>
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<tr>
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<td>3,643,009</td>
<td>655,624</td>
<td>32.91597</td>
<td>79.33577</td>
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Figure 3 Relative location of grid points
The accompanying magnetic-anomaly map of the conterminous United States and adjacent offshore areas was compiled as a cooperative effort by the U.S. Geological Survey and the Society of Exploration Geophysicists (Hinze, 1976). The map is published in two sheets in color showing magnetic-anomaly contours at an interval of 200 gammas (nanoteslas) with supplemental contours at an interval of 100 gammas on an Albers equal-area projection at the scale of 1:2,500,000. The map may be compared directly with the tectonic (U.S. Geol. Survey and Am. Assoc. Petroleum Geologists, 1961), Bouguer gravity anomaly (Am. Geophys. Union, 1964), basement rock (Bayley and Muehlberger, 1968), and geologic (King and Beikman, 1974) maps of the conterminous United States published by the U.S. Geological Survey in cooperation with professional societies.

Hundreds of magnetic-data sources were used in the map compilation. Most of them were total-intensity aeromagnetic-anomaly data; others included total-intensity ground and shipborne magnetic-anomaly data and vertical-intensity ground magnetic-anomaly data. Flight altitudes, directions, and spacings of aeromagnetic surveys varied widely; no attempt was made to analytically continue magnetic-anomaly data to a common altitude. The anomaly data were referenced to numerous magnetic-field datums; however, an attempt was made to adjust most anomaly data to a common magnetic-field datum. On the basis of comparisons with aeromagnetic-anomaly data of the U.S. Naval Oceanographic Office and the National Uranium Resource Evaluation (NURE) program of the Department of Energy, we inferred that the zero level of the compiled map is approximately 1,000 gammas higher than the zero level of data based on the International Geomagnetic Reference Field (IGRF).

Because the quality of the map is limited by the diversity of data types, data-acquisition specifications and the compilation techniques, it is strongly recommended that the map be used only at the 1:2,500,000 publication scale or smaller scales of interest in broad regional investigations. For more detailed work at scales larger than the 1:2,500,000 publication scale, we recommend that original data sources be used.

Compilation involved the following steps: (1) Magnetic anomaly data of a given survey were inspected and, as necessary, were referenced to the IGRF (Fabiano and Peddie, 1969; Barraclough and Fabiano, 1978), adjusted for the time of the survey, and an arbitrary zero datum; (2) contour lines at an interval of 100 or 200 gammas were selected; (3) the map of the selected contour lines was reduced to the 1:1,000,000 compilation scale; (4) the reduced map was placed on an albers equal-area projection master base map of the conterminous United States and offshore areas; (5) near the boundaries of adjacent surveys, contour lines were visually joined as smoothly as possible; and (6) where major discontinuities of anomaly values existed, contoured NURE data were used to guide the connecting of contour lines; and (7) the map at the 1:1,000,000 compilation scale was photographically reduced to the 1:2,500,000 publication scale.

The NURE data, acquired during a 7-year period for the conterminous United States and referenced to the IGRF, provided a reliable base net for controlling the compilation of individual surveys. As an independent check on the validity of the compilation, profiles from the map were compared with a series of north-south aeromagnetic traverses of the U.S. Naval Oceanographic Office (NOO). The traverses were flown in 1976 and 1977 and were spaced approximately one degree of longitude apart across the conterminous United States. This comparison shows that the compiled data agree with the NOO data, after adjustment to the IGRF, to within 100 gammas throughout the country. Magnetic profiles for the 83°W, 90°W, and 119°W meridians comparing total intensity magnetic anomaly data obtained from the NOO survey with those taken from the composite U.S. magnetic anomaly map are shown in Figure 1. The magnetic profiles along each meridian are arbitrarily displaced vertically to effect a better visual comparison.

Individual data sources used in the map compilation are shown on index maps. These index maps are keyed to the "Sources of Data" and "Specifications" (direction, altitude, and spacing of traverses), shown later in this pamphlet. Index maps for the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean are included.

1 Exceptions: IGRF 1965.0 not updated, was removed from total-intensity data of reference F, Oklahoma; reference A, Ohio; and reference 2, Oregon. A field of 9 gammas per mile north and 3 gammas per mile east was removed from vertical-intensity data of reference F, South Dakota. Unknown reference fields were removed from vertical-intensity data of reference H, Missouri, and reference 36, New Mexico. It is not known whether a reference field has been removed from the total-intensity or vertical-intensity data of reference 26, New Mexico.
Acknowledgements

The cooperative arrangement between the U.S. Geological Survey and the Society of Exploration Geophysicists, effected in 1975, resulted in formation of the National Magnetic Anomaly Map (NMAM) Committee, which interacted with a group of U.S. Geological Survey personnel. Current members of the NMAM Committee are:

William J. Hinze, Chairman (Purdue University)
Anthony R. Barringer (Barringer Research Inc.)
Sheldon Brenner (Geometrics)
LeRoy Brow (Exxon Production Research Co.)
James E. Case (U.S. Geological Survey)
Howard L. Cobb (Atlantic Richfield Co.)
John D. Corbett (Anaconda Minerals Co.)
Michael D. Fuller (University of California at Santa Barbara)
James R. Heinzler (Woods Hole Oceanographic Inst.)
Charles E. Heasley (University of Hawaii)
Robert H. Higgs (U.S. Naval Oceanographic Office)
Robert A. Langel (U.S. National Aeronautics & Space Admin.)
H. David MacLean (Gulf Mineral Resources Co.)
Emil J. Mateker, Jr. (Aero Service Co.)
Alfred J. Navazio (Carson Helicopters)
George Podolsky (Kidd Creek Mines Ltd.)
Michael S. Reford (Geoterrex Ltd.)
James A. Schwartz (Gulf Oil Exploration and Production Co.)
Paul H. Serson (Canada Dept. of Energy, Mines & Resources)
Kendall L. Svendsen (U.S. National Oceanic & Atmospheric Admin.)
Eric E. Wicherts (Amoco International Co.)
Richard J. Woid (U.S. Geological Survey)
Isidore Zierz (Phoenix Corp.)
W. Glen Zinn (Moly Corp. Inc.)

Previous members of the committee and their affiliation during their period of participation are:

Joseph W. Berg, Jr. (National Academy of Sciences)
Bimal K. Bhatnacharya (Deceased) (U.S. Geological Survey)
Ernest J. Iuler (U.S. National Aeronautics & Space Admin.)
John F. Landau (Gulf Research & Development Co.)
P. Lawrence (Mobil Oil Corporation)
D. Beatrice Moore (Exxon Co., U. S. A.)
Robert F. McMahon (Chevron Oil Co.)
Robert D. Regan (U.S. Geological Survey)

U.S. Geological Survey coordinators of the cooperative effort were Martin F. Kane, William F. Hanna, Gordon P. Eaton, and Charles J. Zablocki. Richard D. Howey (Chevron Overseas Petroleum Co.) and Val W. Chandler (Minnesota Geological Survey) assisted the Editorial Committee in reviewing selected areas of preliminary versions of the map.

The Amoco Production Company, Chevron Oil Company, Gulf Oil Corporation, and Mobil Exploration and Production Services contributed data to the map. Compilation of the map was performed by Kevin R. Bond, Francis P. Gilbert (Deceased), John R. Kirby, Frederic E. Riggle, and Stephen L. Snyder, all of the U.S. Geological Survey.

References Cited


5. BIBLIOGRAPHY


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PROGRAM AB(INPUT, OUTPUT, TAPE3, TAPE7)
DIMENSION W(132, 132), W2(132, 132), ELEV(132, 132),
ELEV2(132, 132), BA(132, 132), BA2(132, 132), IB(8), IEL(8), IWT(8)

C
C
C

**********************************************************************
C * PROGRAM "AB"
C
C * PROGRAM "AB" IN FILE AB(GP310GR) IS A VARIABLE
C * RADIUS SMOOTHING OPERATOR FOR WEIGHTED POTENTIAL DATA.
C * THE RADIUS OF SMOOTHING IS INCREASED
C * UNTIL IT CONTAINS AT LEAST 6 DATA POINTS WITHIN
C * THE GRID. USING THAT RADIUS, THE VALUE IS RE-
C * COMPUTED. THIS PROCESS IS REPEATED FOR EACH
C * GRID POINT. THE PROGRAM ACCEPTS DATA FROM PROGRAM
C * "GRVGRID". EFFECTIVELY FILLING IN ANY AREAS OF
C * NO DATA AND SMOOTHING AREAS OF LIMITED DATA.
C * AREAS OF HIGH DATA DENSITY REMAIN UNCHANGED.
C
C**********************************************************************

C *** RECOMMENDED COMMANDS TO RUN THIS PROGRAM ON THE
C *** GEORGIA TECH CYBER B SYSTEM:
C *** LGO,,,TAPE3,TAPE7
C *** WHERE
C *** TAPE3=DATA FILE
C *** TAPE7=OUTPUT FILE
MM=132
NN=132

C *** INPUT
READ(3,*,END=10001) NPOINT, DX, OLAT, OLONG, M, N, A, SCALE
READ(3,*,END=10001) ((BA(I,J), ELEV(I,J), W(I,J), I=1, M), J=1, N)
PRINT*, NPOINT, DX, OLAT, OLONG, M, N, A, SCALE
10001 PRINT*, 'INPUT PAST END OF FILE'
WSUM=0.0

C *** CONVERT TO WEIGHTED SUMS
DO 10 I=1, M
DO 10 J=1, N
BA(I,J)=BA(I,J) * W(I,J)
ELEV(I,J)=ELEV(I,J) * W(I,J)
WSUM=WSUM+W(I,J)
10 CONTINUE

C *** COMPUTE RADIUS FOR 6 DATA POINTS
DO 1000 I=1, 132
DO 1000 J=1, 132
IF(W(I,J).GT.0.5) GO TO 901
SW=W(I,J)
DO 700 IR=2, 30
SW1=0
SW2=0
IEND=IR*2-1
DO 600 IIR=1, IEND
INDEX=I-IR+IIR
700 CONTINUE
901 CONTINUE
IF(INDX.LT.1.OR.INDX.GT.132) GO TO 600
JNDX1=J+IR-1
JNDX2=J-IR+1
IF(JNDX1.GT.132) GO TO 599
SW1=W(INDX,JNDX1)+SW1
599
IF(JNDX2.LT.1) GO TO 600
SW2=W(INDX,JNDX2)+SW2
600 CONTINUE
SW=SW1+SW2+SW
SW1=0
SW2=0
IEND=IR*2-3
DO 602 JJR=1,IEND
INDX1=I+IR-1
INDX2=I-IR+1
JNDX=J-IR+JJR+1
IF(JNDX.LT.1.OR.JNDX.GT.132) GO TO 602
IF(INDX1.GT.132) GO TO 601
SW1=SW1+W(INDX1,JNDX)
601 IF(INDX2.LT.1) GO TO 602
SW2=SW2+W(INDX1,JNDX)
602 CONTINUE
SW=SW1+SW2+SW
IF(SW.GT.6)GO TO 701
700 CONTINUE
701 IRAD=IR
C *** COMPUTE NEW WEIGHTED VALUES OF BOUGUER,ELEVATION
C *** AND WEIGHTS
ADIST=FLOAT(IR-1)/2.0
IMIN=MAX0(I-IRAD+1,1)
IMAX=MIN0(I+IRAD-1,132)
JMIN=MAX0(J-IRAD+1,1)
JMAX=MIN0(J+IRAD-1,132)
DO 900 IR=IMIN,IMAX
DO 900 JR=JMIN,JMAX
IF(IR.EQ.I.AND.JR.EQ.J) GO TO 875
DIST=(FLOAT((I-IR)^2+(J-JR)^2))/(ADIST*ADIST)
WT2=1.0/(1+DIST/(ADIST*ADIST))
ELEV2(I,J)=ELEV2(I,J)+ELEV(IR,JR)*WT2
BA2(I,J)=BA2(I,J)+BA(IR,JR)*WT2
GO TO 900
875 ELEV2(I,J)=ELEV2(I,J)+ELEV(I,J)
BA2(I,J)=BA2(I,J)+BA(I,J)
900 CONTINUE
GO TO 1000
901 CONTINUE
W2(I,J)=W(I,J)
BA2(I,J)=BA(I,J)
ELEV2(I,J)=ELEV(I,J)
1000 CONTINUE
C *** RECOMPUTE WEIGHTED AVERAGES
   DO 50 I=1,M
   DO 50 J=1,N
   IF(W2(I,J))50,50,40
   40   BA2(I,J)=BA2(I,J)/W2(I,J)
   ELEV2(I,J)=ELEV2(I,J)/W2(I,J)
   50   CONTINUE

C *** THE FOLLOWING WRITES GRIDDED VALUES IN TABLE FORM TO TAPE 7
C *** OUTPUT IN INTEGER FORMAT FOR USE IN DISPLAY AND ANALYSIS
   REWIND 3
   WRITE(7,*) NPOINT,DX,OLAT,OLONG,M,N,A,SCALE
   DO 2010 I=1,M
   DO 2010 J=1,N,8
   ISTOP=8
   IF(J.EQ.129) ISTOP=4
   DO 2020 K=1,ISTOP
      IB(K)=INT(BA2(I,J+K-1)*10.)
      IEL(K)=INT(ELEV2(I,J+K-1)*10.)
      IWT(K)=INT(W2(I,J+K-1)*1000.)
   2020   WRITE(7,2000) (IB(K),IEL(K),IWT(K),K=1,ISTOP)
   2010   CONTINUE
   2000   FORMAT(24I5)
   STOP
END
ALBERS

ALBERS WILL TAKE LATITUDE AND LONGITUDE AS INPUT AND OUTPUT THE X AND Y VALUES FOR AN ALBERS EQUAL AREA PROJECTION

PROGRAM ALBERT (INPUT, OUTPUT, XY, TAPE5=INPUT, TAPE6=OUTPUT, + TAPE7=XY)
10 DO 31 I=31,32
   ALAT = 1-1
   ALONG = 96.
   CALL ALBERS(X,Y, ALAT, ALONG, 1.0)
   WRITE(7,20)ALAT, ALONG, X, Y
20 FORMAT(3X,'LAT =',1X,F8.2,2X,'LON =',1X,F8.2,2X,'X= ', + F11.2,2X,'Y= ',F11.2)
   CALL ALBERS(X,Y, ALAT, ALONG, -1.0)
   WRITE(7,20)ALAT, ALONG, X, Y
31 CONTINUE
99 STOP
END

SUBROUTINE ALBERS(X,Y, ALAT, ALONG, SGN)

C Assumes 96 degrees west and equator as origin

AN = .602903500628
RSQ = 1.509957717935E+14
RO = 12288033.68296.
RPD = ATAN(1.0)/45.0
EE = .6768657997291054E-03
ARAD = 6378206.4
REFLONG = 96.
SMALL = 1.0E-12
IF (SGN.LT.0) GO TO 30
C*****************
C Formula used to compute constants
C E = first eccentricity (sqrt(A*A-B*B)/A) from Clarke, 1866
C EE = E*E ((A*A-B*B)/A)
C COSPH11 = COS (29.5*RPD)
C COSPH12 = COS (45.5*RPD)
C CSQ1 = COSPH11*COSPH11
C CSQ2 = COSPH12*COSPH12
C SINPH11 = SIN (29.5*RPD)
C SINPH12 = SIN (45.5*RPD)
C SSQ1 = SINPH11*SINPH11
C SSQ2 = SINPH12*SINPH12
C AN = CSQ1/(1.0 - EE*SSQ1) - CSQ2/(1.0 - EE*SSQ2)
C SER1 = SINPH11*(1.0 + EE*SSQ1* (2./3. + EE*SSQ1* (3./5. + + EE*SSQ1* (4./7. + EE*SSQ1* (5./9. + EE*SSQ1* (6./11.))))))
C SER2 = SINPH12*(1.0 + EE*SSQ2* (2./3. + EE*SSQ2* (3./5. + + EE*SSQ2* (4./7. + EE*SSQ2* (5./9. + EE*SSQ2* (6./11.))))))
C AN = AN/(2.0*(1.0-EE)* (SER2 - SER1))
C RHO1SQ = ARAD*ARAD*CSQ1/(AN*AN* (1.0-EE*SSQ1))
C RSQ = RHO1SQ + 2.0*ARAD*ARAD* (1.0-EE)*SER1/AN
C RO = SQRT(ABS(RSQ))
200 REFLong = 96
   SINPHI = SIN(ALAT*RPD)
   SP2 = SINPHI*SINPHI
   SB = SINPHI*(1.0 + EE*SP2*(2./3. + EE*SP2*(3./5. + EE*SP2*
      + (4./7. + EE*SP2*(5./9. + EE*SP2*6./11.)))))
   RHO = 2.0*ARAD*ARAD*(1.0-EE)*SB/AN
   RHO = SQRT(RSQ -RHO)
   THETA = AN*(REFLong - ALONG)
   X = RHO*SIN(THETA*RPD)
   Y = RO - RHO*COS(THETA*RPD)
   GO TO 100
30    THETA=ATAN(X/(RO-Y))
   ALONG = REFLong - THETA/(AN*RPD)
   RHO = (Y-RO)/COS(THETA)
   SB = (RSQ-RHO*RHO) * AN/(2.0*ARAD*ARAD*(1.0-EE))
   ALAT = SB-2.0*EE*SB*SB/3.0
      DO 50 1=1,8
         OLDLAT =ALAT
         A2 = EE*ALAT*ALAT
         ALAT = SB/(1.0+A2*(2./3.+A2*(0.6+A2*(4./7.+A2*
            + (5./9. +A2*6./11.))))))
      WRITE(6,*) I,ALAT,OLDLAT
      IF(ABS(ALAT-OLDLAT).LT.SMALL)GO TO 60
50    CONTINUE
60    ALAT = ASIN(ALAT)/RPD
100   RETURN.
      END
PROGRAM CLEAN(INPUT, OUTPUT, TAPE5, TAPE6, TAPE7)
DIMENSION ALAMIN(8000), ALOMIN(8000), ALAT(8000), ALONG(8000),
+ EL(8000), BOUG(8000), DDLON(8000), DDLAT(8000)

CHARACTER*14 SURV(8000)

10 READ(5,101,END=20)ALAT(I), ALOMIN(I), ALONG(I), ALOMIN(I), EL(I),
+ IBOUG, SURV(I)

101 FORMAT(3X,F3.0,F4.2,2X,F3.0,F4.2,3X,F7.1,20X,I5,A15)

BOUG(I) = FLOAT(IBOUG)/10.

DDLAT(I) = ALAT(I) + ALOMIN(I)/60.

DDLON(I) = ABS(ALONG(I)) + ALOMIN(I)/60.

I = I + 1
GO TO 10

20 ITO=1 = I

30 READ(6,101,END=40)ALAT(I), ALOMIN(I), ALONG(I), ALOMIN(I),
+ EL(I), IBOUG, SURV(I)

BOUG(I) = FLOAT(IBOUG)/10.

DDLAT(I) = ALAT(I) + ALOMIN(I)/60.

DDLON(I) = ABS(ALONG(I)) + ALOMIN(I)/60.

I = I + 1
GO TO 30

40 ITO=2 = I - 1

WRITE (7, 100)

100 FORMAT(' 	 OUTPUT OF CLEAN- 	 WI)

WRITE(7,*) ' LAT 	 LONG 	 ELEV 	 BOUGER 	 SURVEY
+ J1 OR K 	 ADIF'

DO 60 J=2, ITO1

J1=J-1

DO 70 K=J, ITO2

IF(ABS(DDLAT(K) - DDLAT(J1)).GT..0018) GO TO 70

IF(ABS(DDLON(K) - DDLON(J1)).GT..0018) GO TO 70

ADIF = BOUG(J1) - BOUG(K)

WRITE(7,102)ALAT(J1), ALOMIN(J1), ALONG(J1), ALOMIN(J1),
+ EL(J1), BOUG(J1), SURV(J1), J1, ADIF

WRITE(7,102)ALAT(K), ALOMIN(K), ALONG(K), ALOMIN(K), EL(K),
+ BOUG(K), SURV(K), K, ADIF

70 CONTINUE

60 CONTINUE

102 FORMAT (F3.0,1X,F5.2,3X,F3.0,1X,F5.2,3X,F6.1,3X,F6.2,A14,15, +F6.2)

STOP

END
C*************** PROGRAM CLERR
***************
C
PROGRAM CLERR ( FILE1, FILE2, FILEOUT, TAPE6=FILE1, TAPE7=FILE2,
+ TAPE5=FILEOUT)
C
FILE1 CONTAINS THE TOTAL DATA SET (USED AS A STANDARD)
FILE2 CONTAINS THE NEW DATA SET OR A PORTION OF FILE1
TO TEST FOR CONSISTANCY. FIRST CARD IN (15 FORMAT) 0 OR 1, FOR
PREDEFINED OR INTERNALLY COMPUTED AUTOCORRELATION RESPECTIVELY
C
C
C
C READ IN THE REFERENCE DATA IN DOD FORMAT
C
RPD = ATAN(1.0)/ 45.
I = 1
10 READ(6,101,END=20) LAT, LATMN, LON, LONMN, IDATA
101 FORMAT (3X,13,14,2X,13,14,30X,16)
ALAT(I) = FLOAT(LAT) + FLOAT(LATMN)/ 6000.
ALONG(I) = FLOAT(LON) + FLOAT(LONMN)/ 6000.
DAT(I) = FLOAT(IDATA)/ 100.
I = I+1
GOTO 10
20 IFST= I-1
C
C READ IN THE FILE TO BE TESTED
C - OPTAUT = : IF THIS IS GREATER THAN 0 THEN COMPUTES AUTOCORRELATION
C FROM DATA ELSE IT USES PREDEFINED AUTOCORRELATION.
C
READ(7,100,END=30) OPTAUT
100 FORMAT (I5)
21 READ(7,101,END=30) LAT, LATMN, LON, LONMN, IDATA
ALAT(I) = FLOAT(LAT) + FLOAT(LATMN)/ 6000.
ALONG(I) = FLOAT(LON) + FLOAT(LONMN)/ 6000.
DAT(I) = FLOAT(IDATA)/ 100.
I = I+1
GOTO 21
IEND = I-1

CALCULATE THE MEAN AND VARIANCE OF THE TOTAL DATA SET

SUMX=0.0
SUMXX=0.0
AVLAT= 0.0
AVLONG= 0.0
DO 35 I= 1,IEND
   AVLAT= AVLAT + ALAT(I)
   AVLONG= AVLONG + ALONG(I)
   SUMX= SUMX + DAT(I)
   SUMXX= SUMXX + DAT(I)*DAT(I)
35 CONTINUE

AMEAN= SUMX/FLOAT(IEND)
VAR= (SUMXX/FLOAT(IEND)) - AMEAN*AMEAN
OLAT= AVLAT/FLOAT(IEND)
OLON= AVLONG/FLOAT(IEND)
WRITE(5,77) VAR,OLAT,OLON,AMEAN,IEND

77 FORMAT (6HVAR = ,F8.3/7HOLAT = ,F10.4/7HOLON = ,F10.4/
+8HAMEAN = ,F8.3/7HIEND = ,I6)

CONVERT TO MAP DISTANCES IN KILOMETERS

DO 38 I= 1,IEND
   CALL MAPS (ALAT(I),ALONG(I),OLAT,OLON)
38 CONTINUE

IF(OPTAUT.GT.0) GO TO 88
DO 39 1=1,30
   II=I-1
39 AUTO(I)=COS(II*90*RPD/15.) * EXP(II*90*RPD/15.)
GO TO 89

FIND THE AUTOCORRELATION FUNCTION OF THE DATA

CALL AUTOCF (ALAT,ALONG,AUTO,IEND,VAR,AMEAN,DAT)

SORT IN ORDER OF LATITUDE

DO 103 I= 2,IEND
   IS= I-1
   DO 90 J= I,IEND
      IF (ALAT(IS) .LE. ALAT(J)) GOTO 90
      IS= J
90 CONTINUE

ALATS= ALAT(IS)
ALONGS= ALONG(IS)
DATS= DAT(IS)
IM1= I-1
ALAT(IS)= ALAT(IM1)
ALONG(IS)= ALONG(IM1)
DAT(IS)= DAT(IM1)
ALAT(IM1) = ALATS
ALONG(IM1) = ALONGS
DAT(IM1) = DATS

103 CONTINUE

C
COMPUTE THE EXTRAPOLATED VALUE BY THE DISTANCE WEIGHTED
SUM OF THE EIGHT NEAREST POINTS
C
C
REWIND FILE
C
REWIND 7
ISTOP = IEND - IFST
DO 200 II = 1, ISTOP
    READ(7, 101, END = 201) LAT, LATMN, LON, LONMN, IDATA
    TLAT = FLOAT(LAT) + FLOAT(LATMN) / 6000.
    TLONG = FLOAT(LON) + FLOAT(LONMN) / 6000.
    TDAT = FLOAT(IDATA) / 100.
    CALL MAPS (TLAT, TLONG, OLAT, OLON)

C
FING START INTEGER FOR THE SEARCH
C
DO 220 I = 1, IEND
    IF (TLAT .LE. ALAT(I)) GOTO 221
    CONTINUE
220    ISTART = 1 - 4
    IF (ISTART .LT. 1) ISTART = 1

C
COMMENCE SEARCH FOR EIGHT NEAREST POINTS
C
IF (ISTART .GT. (IEND - 9)) ISTART = IEND - 9
JJ = 1
DO 250 J = 1, 9
    J1 = J - 1 + ISTART
    DLAT(JJ) = ALAT(J1)
    DLON(JJ) = ALONG(J1)
    R(JJ) = (TLAT - ALAT(J1))**2 + (TLONG - ALONG(J1))**2
    D(JJ) = DAT(J1)
    IF (R(JJ) .LT. .01 .AND. J .EQ. JJ) GOTO 250
    JJ = JJ + 1
250 CONTINUE
AMAXRR = 0.0
DO 260 K = 1, 8
    IF (R(K) .LT. AMAXRR) AMAXRR = R(K)
260 CONTINUE

KINC = 4
DO 300 K = 1, IEND
    KINC = KINC + 1
    K1 = I - KINC
    IF (K1 .LT. 1) GOTO 319
    RTTEST = (TLAT - ALAT(K1))**2 + (TLONG - ALONG(K1))**2
    IF (RTTEST .GE. AMAXRR) GOTO 320
DO 310 KK = 1,8
   IF (R(KK) .LT. AMAXRR) GOTO 310
   AMAXRR = RTEST
   R(KK) = RTEST
   D(KK) = DAT(K1)
   DLAT(KK) = ALAT(K1)
   DLON(KK) = ALONG(K1)
   GOTO 320
310 CONTINUE

319 K1 = K + KINC

320 K2 = K + KINC
   IF (K2 .GT. IEND) GOTO 329
   RTEST = (TLAT - ALAT(K2))**2 + (TLONG - ALONG(K2))**2
   IF (RTEST .GE. AMAXRR) GOTO 330
   DO 340 KK = 1,8
      IF (R(KK) .LT. AMAXRR) GOTO 340
      AMAXRR = RTEST
      R(KK) = RTEST
      D(KK) = DAT(K2)
      DLAT(KK) = ALAT(K2)
      DLON(KK) = ALONG(K2)
      GOTO 330
340 CONTINUE
329 K2 = K1
330 ATM1 = (TLAT - ALAT(K1))**2
   ATM2 = (TLAT - ALAT(K2))**2
   IF (AMAXRR .LT. ATM1 .AND. AMAXRR .LT. ATM2) GOTO 400
300 CONTINUE
C
C COMPUTE THE EXTRAPOLATED VALUE (SD)
C
C FIRST COMPUTE WEIGHTS. THEN NORMALIZE
C
400 SWT = 0.0
   DO 410 J = 1,8
      W(J) = 1/(1.0 + R(J)/4.0)
      SWT = SWT + W(J)
410 CONTINUE
   DO 411 J = 1,8
      W(J) = W(J)/SWT
411 CONTINUE
C
SD = 0.0
S1 = 0.0
S2 = 0.0
S3 = 0.0
   DO 450 KI = 1,8
      SD = SD + W(KI)*D(KI)
      S1 = S1 + W(KI)*W(KI)*.09
      S2 = S2 + 2.0*W(KI)*AUT(R(KI),AUTO)
      DO 450 KII = 1,8
         RR = (DLAT(KII) - DLAT(KI))**2 + (DLON(KII) - DLON(KI))**2
         S3 = S3 + W(KI)*W(KII)*AUT(RR,AUTO)
450 CONTINUE
SUBROUTINE AUTOCF (X, Y, AUTO, IEND, VAR, AMEAN, DAT)
DIMENSION X(IEND), Y(IEND), AUTO(30), NUM(30), DAT(IEND), AM(30)

EXPECT 1 KM SEPARATION FOR THE DATA AND COMPUTE THE AUTOCORRELATION OUT TO 30 KM.

DO 100 I = 2, IEND
   ISTOP = MINO(I + 50, IEND)
   DO 100 J = I, ISTOP
      NX = SQRT((X(I - 1) - X(J))**2 + (Y(I - 1) - Y(J))**2) + 1.5
      IF (NX .GT. 30) NX = 30
      AUTO(NX) = AUTO(NX) + (DAT(I - 1) * DAT(J))
      NUM(NX) = NUM(NX) + 1
      AM(NX) = AM(NX) + DAT(I - 1) + DAT(J)
   100 CONTINUE

DO 200 I = 1, 30
   IF (NUM(I) .EQ. 0) GOTO 200
   AUTO(I) = AUTO(I) / FLOAT(NUM(I)) - (AM(I) / FLOAT(2 * NUM(I)))**2
200 CONTINUE

WRITE(5, 105)
WRITE(5, 106) (AUTO(I), NUM(I), I = 1, 30)
105 FORMAT (1X, 'AUTOCORRELATION FUNCTION USED')
106 FORMAT (1X, 6HAUTO =, F10.2, 5X, 8HNUMBER =, I6)
SMOOTH THE AUTOCORRELATION FUNCTION

SAUT = AUTO(1)
DO 300 I = 2, 29
   SAUT2 = AUTO(I)
   AUTO(I) = (SAUT*NUM(I-1) + 2*AUTO(I)*NUM(I) + AUTO(I+1)*NUM(I+1)) / 
             (NUM(I-1) + 2*NUM(I) + NUM(I+1))
   SAUT = SAUT2
300 CONTINUE
WRITE(5,97)
WRITE(5,106) (AUTO(I), NUM(I), I = 1, 30)
97 FORMAT ('SMOOTHED AUTOCORRELATION FUNCTION ')
C
RETURN
END

FUNCTION AUT(R, AUTO)
DIMENSION AUTO(30)
IR = SQRT(R) + 1.0
IF (IR .GT. 30) IR = 30
AUT = AUTO(IR)
RETURN
END

FUNCTION COLAT(P)
COLAT = 1.570796327 - P + (0.3393028E-2) * SIN(2. * P)
COLAT = COLAT - (0.47996E-5) * SIN(4. * P) + (0.8469E-8) * SIN(6. * P)
RETURN
END

SUBROUTINE MAPS(ALAT, ALONG, OLAT, OLONG)
CF = 0.0174532925
PI = 3.141592653
AK = 6688.3748
AL = 0.63305171
ALAT = ALAT * CF
ALONG = (OLONG - ABS(ALONG)) * CF
R = COLAT(ALAT) / 2.
R = AK * (TAN(R) ** AL)
X = R * SIN(AL * ALONG)
P30 = OLAT * CF
Z30 = COLAT(P30)
R30 = AK * (TAN(Z30/2.) ** AL)
Y = R30 - R * COS(AL * ALONG)
ALONG = X * 0.072960 * 25.4
ALAT = Y * 0.072960 * 25.4
RETURN
END
PROGRAM SNGGRID(DATA3,DATA7,DATA6,INPUT,OUTPUT,TAPE3=DATA3, +TAPE7=DATA7,TAPE6=DATA6,TAPE5=INPUT)

C TO GET THIS PROGRAM:/GET,SNGGRID/UN=GPLIBGR
C*****************************************************************************
C
* SNGGRID
C
* SNGGRID WILL GENERATE A NEW GRID OR UPDATE AND REPLACE
* AN OLD GRID OF EQUALLY SPACED VALUES INTERPOLATED FROM
* RANDOMLY SPACED DATA. GRIDS FOR THE DATA AND WEIGHTS
* ARE GENERATED ON THE BASIS OF A DISTANCE WEIGHTED AVE-
* RAGE OF DATA WITH NEIGHBORING AREAS DEFINED BY THE GRID
* POINTS. 
C
*******************************************************************************/
C
RECOMMENDED COMMANDS TO RUN THIS PROGRAM ON THE GEORGIA TECH CYBER SYSTEM:
FTN5,I=SNGGRID,L=0 (TO COMPILE PROGRAM)
LGO,TAPE3,TAPE7,TAPE6,TAPE5
WHERE
TAPE3 = FILE CONTAINING GRID FROM PREVIOUS RUN. THE FILE WILL BE
OVER WRITTEN BY NEW GRIDS. (SAVE BACKUP COPY BEFORE
RUN OR CHECK OUTPUT CAREFULLY BEFORE REPLACING.)
TAPE5 = INPUT FROM SCREEN
TAPE6 = CONTAINS LINE PRINTER LISTING OF GRID AND NEW DATA INSERTED
TAPE7 = FILE CONTAINING NEW DATA IN DOD FORMAT
C
PROGRAM SNGGRID INTERPOLATES BOUGUER ANOMALIES AND GRAVITY POINT
DEVIATION INTO A GRID WITH DIMENSIONS M X N. M IS THE NUMBER
OF COLUMNS ON THE X HORIZONTAL SCALE AND N IS THE NUMBER OF
ROWS ON THE Y HORIZONTAL SCALE. TO CHANGE THE MAXIMUM
DIMENSIONS IT IS NECESSARY TO CHANGE THE VALUES IN THE DIMENSION
STATEMENT. THOSE IN THE VARIABLE DEFINITION STATEMENTS (MM=&NN=)
MUST BE SET EQUAL TO THE DIMENSIONS IN THE DIMENSION STATEMENT,
WHERE M IS THE FIRST NUMBER IN PARENTHESES, AND N IS THE SECOND.
C
DIMENSION W(132,132),BA(132,132),TW(4,4),T(500)
MM=132
NN=132
DX=0
RAD=ATAN(1.)/45.
C
TAPE3 CONTAINS GRIDDED VALUES FROM THE LAST RUN. IF TAPE3
IS EMPTY, THE PROGRAM GOES TO 1, WHERE NEW DATA ARE READ.
C
THE FIRST CARD IMAGE OF TAPE 3 CONTAINS THE FOLLOWING INFORMATION
IN FREE FIELD FORMAT:
NPOINT = # OF POINTS USED TO GENERATE PREVIOUS GRID
DX = INCREMENT OF GRID IN KILOMETERS IN THE X DIRECTION
DY = INCREMENT OF GRID IN KILOMETERS IN THE Y DIRECTION
OLAT = LATITUDE OF ORIGIN OF GRID (SW CORNER WITH NO ROTATION)

A-6-14
C (DECIMAL DEGREES)
C OLONG = LONGITUDE OF ORIGIN OF GRID (SW CORNER WITH NO ROTATION)
C (DECIMAL DEGREES)
C M = NUMBER OF COLUMNS (EAST-WEST DIRECTION)
C N = NUMBER OF ROWS (NORTH-SOUTH DIRECTION)
C A = ANGLE OF ROTATION ABOUT THE ORIGIN (POSITIVE CLOCKWISE)
C SCALE = SCALE AT WHICH MAP IS TO BE PLOTTED
C DATA = M X N DATA POINTS IN FREE FIELD FORMAT
READ(3,*,END=10000) NPOINT,DX,DY,OLAT,OLOGIN,M,N,A,SCALE

10000 IF(E0F(3))1,2,1

2 READ(3,665,END=10001) AA
DO 143 J=1,N
DO 143 I=1,M,8
READ(3,666,END=10001)(BA(I+K-1,J),K=1,8)
143 CONTINUE
READ(3,665,END=10001) AA
DO 144 J=1,N
DO 144 I=1,M,8
READ(3,666,END=10001)(W(I+K-1,J),K=1,8)
144 CONTINUE
10001 CONTINUE
665 FORMAT(A30)
666 FORMAT(8F10.2)
C C PRINTS VALUES FROM OLD GRID (OLD BOUG, OLD WTS)
C FOR REVIEW AND REFERENCE.
C PRINT*, 'DO YOU WISH A LINE PRINTER INTEGER PLOT? ENTER Y OR N'
READ(5,*) IANS
IF (IANS.EQ.N) GO TO 3
C WRITE(6,102) NPOINT
102 FORMAT(1H1, 'OLD GRID CONTAINS', I6, ' POINTS', //)
103 FORMAT(1H1, 'OLD BOUGUER ANOMALIES * 10', //)
WRITE(6,103)
CALL PRGRID(BA,10.,M,N,MM,NN)
105 FORMAT(1H1, 'OLD WEIGHTS * 100', //)
WRITE(6,105)
CALL PRGRID(W,100.,M,N,MM,NN)
3 DO 10 I=1,M
DO 10 J=1,N
BA(1,J) = BA(1,J) * W(I,J)
10 CONTINUE
1 WRITE(6,106)
106 FORMAT(1H1, 'DATA INSERTED INTO GRID THIS PASS', //)
C
THE FOLLOWING READS THE FIRST CARD OF THE NEW DATA FILE

DX = INCREMENT OF GRID IN KILOMETERS IN THE X DIRECTION
DY = INCREMENT OF GRID IN KILOMETERS IN THE Y DIRECTION
OLAT = LATITUDE OF ORIGIN OF GRID (SW CORNER WITH NO ROTATION)
     (DEGREES)
OLONG = LONGITUDE OF ORIGIN OF GRID (SW CORNER WITH NO ROTATION)
     (DEGREES)
M = NUMBER OF COLUMNS (EAST-WEST DIRECTION)
N = NUMBER OF ROWS (NORTH-SOUTH DIRECTION)
A = ANGLE OF ROTATION ABOUT THE ORIGIN (POSITIVE CLOCKWISE)
SCALE = SCALE AT WHICH MAP IS TO BE PLOTTED
DATA = M X N DATA POINTS IN STANDARD DOD FORMAT

IF (DX.EQ.0) GO TO 132
READ(7, *) DX, DY, OLAT, OLONG, IM, IN, TA, TS

TEST FOR CONSISTENCY
IF (TDX.NE.DX) GO TO 131
IF (TOLAT.NE.OLAT) GO TO 131
IF (TOLONG.NE.OLONG) GO TO 131
IF (IM.NE.M) GO TO 131
IF (IN.NE.N) GO TO 131
IF (TA.NE.A) GO TO 131
IF (TS.NESCALE) GO TO 131
GO TO 133

131 PRINT*, 'GRID PARAMETERS ARE NOT THE SAME AS ON THE'
     + PREVIOUS RUN. DO YOU WISH TO CONTINUE? (Y OR N)
READ(5,130) IANS
130 FORMAT(A1)
IF (IANS.EQ.N) STOP
GO TO 133

132 READ(7, *) DX, DY, OLAT, OLONG, M, N, A, SCALE

FIND THE NORTHING AND EASTING (TMOLAT, TMOLONG) OF THE ORIGIN
LONGITUDE AND ORIGIN LATITUDE (OLONG, OLAT)

133 DOLONG=OLONG
DOLAT=OLAT
CHARLESTON GRIDS ARE ZONE -17
ZONE=INT((186-NINT(OLONG))/6)
CHANGE ZONE TO CORRESPONDED TO AREA OF MAP (KEEP NEGATIVE TO
C FIX)
CALL LLUTM(TMOLAT, TMOLONG, DOLAT, DOLONG, -17)
PRINT*, 'TMOLONG=', TMOLONG, ' TMOLAT=', TMOLAT, 'DOLONG=', DOLONG,
C + 'DOLAT=', DOLAT

**11 READ(7, 107, END=10003) ALAT, ALONG, BOUG
THE FOLLOWING LINES ARE FOR READING DATA
FROM SPECIAL TAPES THAT CONTAIN DATA USED IN THE
132 KM LENGTH CHARLESTON, S.C. GRID.
TO RUN THE ORIGINAL SNGGRID, COMMENT THESE LINES
AND REMOVE THE "***" FROM THE ORIGINAL LINES.

C* READ ERPI DATA (IN ALBERS PROJECTION) AND
C* CONVERT TO A NEW CHARLESTON GRID (IN TRANSVERSE MERCATOR
C* PROJECTION
READ(7,100) NCOLS,NROWS,XMIN,XMAX,YMIN,YMAX,RNULL

100 FORMAT (215,5(2X,E12.5))

YMET= YMIN

C THIS ZEROES THE ARRAY OF TEMPORARY VALUES
C 777 DO 390 I= 1,397
T(I)= 0.0
390 CONTINUE

C SET XMET BACK ONE X INCREMENT
XMET= XMEN - 4000.
C LOOP TO READ IN THE 50 LINES OF A BLOCK.
C THERE ARE EIGHT VALUES PER LINE.
C
DO 400 I= 1,400,8
READ(7,150,END=10003) T(I),T(I+1),T(I+2),T(I+3),
+ T(I+4),T(I+5),T(I+6),T(I+7)

150 FORMAT(8E10.4)

400 CONTINUE

C LOOP OVER EACH BLOCK, TEST IF THE POINT IS IN THE GRID.
C
DO 600 K= 1,396
XMET= XMEN + 4000.
IF(T(K) .EQ. RNULL) GOTO 600
CALL ALBERS (XMET,YMET,ALAT,ALONG,-1.)

BOUG= T(K)
C WRITE(6,*)ALAT,ALONG,BOUG
10003 IF (EOF(7))12,4,12
107 FORMAT(26X,2F8.3,6X,F6.2)
C
NEXT, COMPUTES X AND Y WHERE + WEST, + NORTH
C
DXX = ABS(ALONG)
DYY = ALAT
C WRITE(6,601)DYY
601 FORMAT('DYY=',F12.4)
C
C NEXT DETERMINE THE DISTANCE IN KILOMETERS BETWEEN (X,Y) AND (OLONG, OLAT) FOR UTM PROJECTION
C
CALL LLUTM(AN1,E1,DYY,DXX,-17)
C WRITE(6,602)AN1,TMOLAT
602 FORMAT('AN1=',F15.4,'TMOLAT=',F15.4)
Y = AN1-TMOLAT
X = E1-TMOLONG
C WRITE(6,500)X,Y
C500 FORMAT('X=',F10.3,'Y=',E15.6)
C
C NEXT, ROTATE GRID BY (A) DEGREES. THE NEW AXIS IS ROTATED (A) DEGREES
C (B) RADIANS CLOCKWISE FROM OLD AXIS ABOUT THE ORIGIN.
IF (A.EQ.0) GO TO 27
  B=A*RAD
  XSAVE=X*COS(B)-Y*SIN(B)
  YSAVE=X*SIN(B)+Y*COS(B)
  X=XSAVE
  Y=YSAVE
C
C THE FOLLOWING PUTS OLAT, OLONG AT PT 3,3 OF GRID
C
27  X = X/(DX*1000.) + 3
    Y = Y/(DY*1000.) + 3
C NEXT, INTERGERIZES X AND Y TO GIVE GRID COORDINATES
    IX=X
    IY=Y
C WRITE(6,501)IX,IY
501 FORMAT('IX=',I5,'IY=',I5)
C
C THE FOLLOWING DETERMINES IF A PT IS OUT OF RANGE
C IF IT IS, SKIP IT.
C
****** TO RUN THE ORIGINAL SNGGRID, CHANGE 600 TO 11
****** IN THE NEXT TWO LINES.
    IF(IABS(IX-M/2).GT.M/2-2)GO TO 600
    IF(IABS(IY-N/2).GT.N/2-2)GO TO 600
    NPOINT = NPOINT + 1
C
C THE FOLLOWING WRITES THE OUTPUT, STARTING WITH
C THE VALUES READ FROM TAPE5
C
C WRITE(6,108) ALAT,ALONG,BOUG
108 FORMAT(2F8.3,F6.2)
    CALL CALTW(TW,X,Y,DX,DY)
C WRITE(6,502)TW
502 FORMAT('TW=',F10.3)
    DO 20 I=1,4
    DO 20 J=1,4
   IXI = IX-2+I
   JYJ = IY-2+J
   W(IXI,JYJ) = W(IXI,JYJ) + TW(I,J)
   BA(IXI,JYJ) = BA(IXI,JYJ) + BOUG*TW(I,J)
20 CONTINUE
*** GO TO 11
****** TO RUN THE ORIGINAL SNGGRID, REMOVE "***" FROM
****** PREVIOUS LINE AND COMMENT THE NEXT TWO LINES.
600 CONTINUE
C INCREMENT YMET FOR THE NEXT BLOCK
C
YMET = YMET + 4000.
GOTO 777
12 CONTINUE
    DO 50 I=1,M
    DO 50 J=1,N
       IF(W(I,J))50,50,40
50    BA(I,J) = BA(I,J)/W(I,J)
    CONTINUE
C
    NEXT, CONTINUES TO WRITE TO TAPE6.
C (1) # OF PTS IN NEW GRID
C (2) NEW BOUGER ANOMALIES TIMES 10
C (4) NEW WEIGHTS TIMES 100
C
WRITE(6,109) NPOINT
109 FORMAT(1H1,'NEW GRID CONTAINS',I6,' POINTS',/)
WRITE(6,110) SCALE
110 FORMAT(1H1,'NEW ANAMOLIES * SCALE',E11.4,/) CALL PRGRID(BA,SCALE,M,N,MM,NN)
WRITE(6,112) SCALE
112 FORMAT(1H1,'NEW WEIGHTS * SCALE',F8.1,/) CALL PRGRID(W,SCALE,M,N,MM,NN)
C
THE FOLLOWING WRITES GRIDDED VALUES IN TABLE FORM TO TAPE3
C
REWIND 3
WRITE(3,*) NPOINT,DX,DY,OLAT,OLONG,M,N,A,SCALE
WRITE(3,111) SCALE
111 FORMAT('NEW ANOMALIES')
    DO 149 J=1,N
    DO 149 I=1,M,8
       WRITE(3,666)(BA(I+K-1,J),K=1,8)
149 CONTINUE
WRITE(3,113) SCALE
113 FORMAT('NEW WEIGHTS')
    DO 190 J=1,N
    DO 190 I=1,M,8
       WRITE(3,666)(W(I+K-1,J),K=1,8)
190 CONTINUE
STOP
END A-6-19
SUBROUTINE CALTW(TW,X,Y,DX,DY)
C THIS SUBROUTINE ASSUMED THAT THE WEIGHTS ARE COMPUTED AS
C IF IN A SQUARE GRID (DX=DY)
    DIMENSION TW(4,4)
    A = 0.5
    SW = 0.0
    IX = X
    IY = Y
    X = X-IX
    Y = Y-IY
    DO 10 IX=1,4
        DO 10 IY=1,4
            X2=(2.0-IX+X)*(2.0-IX+X)
            Y2=(2.0-IY+Y)*(2.0-IY+Y)
            RR=X2+Y2
            TW(IX,IY)=1.0/(RR/(A*A)+1.0)
        10     SW=SW+TW(IX,IY)
    DO 20 IX=1,4
        DO 20 IY=1,4
            TW(IX,IY) = TW(IX,IY)/SW
        20     RETURN
    END

SUBROUTINE PRGRID(A,SCALE,M,N,MM,NN)
    DIMENSION K(32),A(MM,NN)
    DO 20 L=1,M,32
        L1 = L
        L2 = L + 31
        IF(L2.GT.M) L2=M
        DO 30 IJ=1,N
            J = N-IJ+1
            DO 40 I=L1,L2
                40      K(I-L1+1)=SCALE*A(I,J)
        30     L3=L2-L1+1
        30     WRITE(6,101) (K(I),I=1,L3)
        20     CONTINUE
    101    FORMAT(1X,/,32I4)
    RETURN
END
***** PLTX *****

When given the latitude and longitude of a point as input, program PLTX will output the grid indices corresponding to the point for each of the four grids defined for the Charleston study. Program PLTX (INPUT, OUTPUT, XY, TAPE5 = INPUT, TAPE6 = OUTPUT, + TAPE7 = XY)

DIMENSION IX(4), IY(4)
WRITE (6,7)
7 FORMAT ('ENTER POINT IN DECIMAL DEGREES, (LAT, LON)')
4 READ (5, *, END=99) ALAT, ALONG
CALL LATTOX (ALAT, ALONG, AN, AE, IX, IY)
8 FORMAT ('OUTPUT OF LATTOX')
WRITE (7,9)
9 FORMAT ('--------------------------------------')
WRITE (7,10) ALAT, ALONG
10 FORMAT ('LATITUDE=', F15.6, 'LONGITUDE=', F15.6)
WRITE (7,40)
40 FORMAT ('--------------------------------------')
DO 60 I=1, 4
   WRITE (7,61) I, IX(I), IY(I)
60 CONTINUE
GO TO 4
99 STOP
END

SUBROUTINE LATTOX (ALAT, ALONG, AN, AE, IX, IY)
DIMENSION R(4), DX(4), IX(4), IY(4)
REAL N, NP
IF (OLAT .NE. 0.0) GO TO 10

DECLARE CONSTANTS OF THE CHARLESTON GRID DEFINITIONS
OLAT = ORIGIN LATITUDE, OLONG = ORIGIN LONGITUDE,
DX = GRID INCREMENT IN METERS, R = DISTANCE FROM ORIGIN IN METERS
ANG = ANGLE OF GRID ROTATION, CLOCKWISE

OLAT = 33.125
OLONG = 81.25
DATA DX/1000., 4000., 8000., 31.25/
DATA R/0., 62500., 444500., 484.375/
RPD = ATAN(1.0)/45.
ANG = 52*RPD
CALL LLUTM(ON,OE,OLAT,OLONG,-17.)
WRITE(7,60) ON,OE
60 FORMAT(10H ORIGIN N=,F15.2,10H ORIGIN E=,F15.2)
10 CALL LLUTM(N,E,ALAT,ALONG,-17.)
WRITE(7,61) N,E
61 FORMAT(10H POINT N =,F15.2,10H POINT E =,F15.2)
N=N-ON
AN=N
E=E-OE
AE=E
NP=E*SIN(ANG)+N*COS(ANG)
EP=E*COS(ANG)-N*SIN(ANG)
DO 50 I=1,4
   IY(I)=IFIXMNP+R(I)+DX(I)/2)/DX(I)+1
   IX(I)=IFIXMEP+R(I)+DX(I)/2)/DX(I)+1
50 CONTINUE
RETURN
END

C
SUBROUTINE LLUTM(ZN,ZE,ZLAT,ZLON,ZONE)
C********
C
CONVERTS LATITUDE AND LONGITUDE IN DEGREES
TO UTM NORTH AND EAST IN METERS
C
C********
IMPLICIT DOUBLE PRECISION (A-Y)
DIMENSION NCO(8),LCO(10)
C********
LAT=ZLAT
LON=ZLON
AZONE=ZONE
KZERO=.9996D0
SEMAJ=6378206.4D00
SEMIN=6356583.8D00
ECC=8.22718542230030D-02
ECCSQ=6.76865799729105D-03
EPSQ=6.81478494591504D-03
NC0(1)=6.367399689169782D 06
NC0(2)=-3.250286241790479D 04
NC0(3)=1.384048366716706D 02
NC0(4)=-7.33538130601429D-01
NC0(5)=4.219413411982918D-01
NC0(6)=-2.529287942342808D-05
1+1D:1(7)=1.556058285276589D-07
NO0(8)=-9.738474374730020D-10
LC0(1)=1.0000000000000000D0
LC0(2)=-1.3537315994582110D-02
LC0(3)=9.1629462168584310D-05
LC0(4)=-3.095662638412468D-05
LC0(5)=4.148716543194615D-07
LC0(6)=-1.268441397827776D-07
LC0(7)=2.158262546309650D-09
LC0(8)=-6.173915584213417D-10
LC0(9)=1.190710620936894D-11
LC0(10)=-3.157184252484188D-12
RPD = ATAN(1.) / 45.
P1 = 3.14159265358979300
F T P E R M = 3.2808333333333300
S I N S E C = 4.84813681109520 - 6
IF (AZONE .GE. 0) AZONE = (186DO - LON) / 6DO
IF (LAT .EQ. PHI) GO TO 2
PHI = LAT
ARG = LAT * RPD
COSPHI = D COS (ARG)
COSSQ = COSPHI ** 2
SINPHI = D SIN (ARG)
SINSG = SINPHI ** 2
TANSQ = SINSG / COSSQ
TANPHI = SINPHI / COSPHI
NPHIK = KZERO * SEMAJ / DSQRT (1DO - ECCSQ * SINSG)
FILAT = ((((((NC0(8) * COSSQ + NC0(7)) * COSSQ + NC0(6)) * COSSQ + NC0(5))
+ * COSSQ + NC0(4)) * COSSQ + NC0(3)) * COSSQ + NC0(2)) * COSPHI * SINPHI
+ + NC0(1) * ARG) * KZERO

2 CONTINUE

CENLON = (30 - DABS (AZONE)) * 6DO + 3DO
P = (CENLON - LON) * RPD
PSCS = P * P * COSSQ
ESC = EPSQ * COSSQ
FIIIP = ((4DO * ESCS + 9DO) * ESCS + 5DO - TANSQ) * 30DO
A6P = (TANSQ - 58DO) * TANSQ + 6002 * ESCS - 33000 * EPSQ + 61DO
N = ((A6P * PSCS + FIIIP) * PSCS + 36000) * PSCS * TANPHI * NPHIK / 720DO + FILAT
FVP = (1DO - TANSQ + ESCS) * 20DO
B5F = (TANSQ - 18DO) * TANSQ + 72DO * ESCS - 58DO * EPSQ + 5DO
E = ((B5F * PSCS + FVP) * PSCS + 120DO) * P * COSPHI * NPHIK /
+ 120DO + 5000000DO
ZN = SNGL (N)
ZE = SNGL (E)
RETURN

END

PROGRAM PXTL (LATLON, INPUT, OUTPUT, TAPE7 = LATLON, TAPE5 = INPUT,
+ TAPE6 = OUTPUT)

1 PRINT*, 'ENTER GRID NUMBER (1=128KM, 2=256KM, 3=1028KM,
+ 4=LANDSAT), INDEX TO SE, INDEX TO NE'
READ (5, *) IGRIDN, X, Y
IX = X
IY = Y
IF (IGRIDN.GT.4 .. OR. IGRIDN.LT.1.) GO TO 9
CALL XTOLAT (ALAT, ALONG, AN, AE, IX, IY, IGRIDN)
WRITE (7, *) '------------------'
WRITE (7, 45)
45 FORMAT ('OUTPUT OF XTOLAT')
WRITE (7, 47)
47 FORMAT ('------------------')
WRITE (7, 50) IGRIDN

A-6-23
SUBROUTINE CALCEOGRID

IMPLICIT DOUBLE PRECISION (A-Y)

DIMENSION R(4), DX(4)
DATA R/0., 62500., 444500., 484.375/
DATA DX/1000., 4000., 8000., 31.25/
ON=3664980.84
OE=476678.49
RPD=ATAN(1.0)/45.
A=-52*RDP
AN=FLOAT(Y-1)*DX(1)-R(1)
AE=FLOAT(X-1)*DX(1)-R(1)
AES=AE*COS(A) - AN*SIN(A)
AN=AE*SIN(A) + AN*COS(A)
AE=AES
AN = AN + ON
AE = AE + OE
CALL UTMLL(AN,AE,ALAT,ALONG,17.)
RETURN
END

SUBROUTINE UTMLL(ZN,ZE,ZLAT,ZLON,ZONE)

C*********
IMPLICIT DOUBLE PRECISION (A-Y)
DIMENSION NCO (8), LCO (10)
C*********

N = ZN
AZONE = ZONE
E = ZE
LAT = ZLAT
LON = ZLON
KZERO=.9996D0
SEMAJ=6378206.4000
SEMIN=6356583.8000
ECC=8.227185422300300002
ECCSQ=6.76865797291054D-03
EPSQ=6.8147849459150420-03
NCO (1)=6.367399689169782D 06
NCO (2)=-3.2502862417904790-01
NCO (3)=4.219413411982918D-03
NCO (4)=-7.3353881306014290-01
NCO (5)=-2.529287942342808D-05
NCO (6)=1.5560582852765890-07
NCO (7)=-9.7384743747300200-10
LCO (1)=1.0000000000000000D 00

A-6-24
LCO(2) = -1.353731599458211D-02
LCO(3) = 9.162946216858431D-05
LCO(4) = -3.095662638412468D-05
LCO(5) = 4.148716543194615D-07
LCO(6) = -1.268441397827760D-07
LCO(7) = 2.158262546320965D-09
LCO(8) = -6.173915584213417D-10
LCO(9) = 1.190710620936894D-11
LCO(10) = -3.15718425248188D-12
RPD = ATAN(1.) / 45.
N = 3.141592653589793D0
FTPERM = 3.280833333333330D0
SINSEC = 4.84813681109520D-06
IF (N.EQ.FILAT) GO TO 2
FIK = N / KZERO
ARG = FIK / NC0(1)
COSPHI = DCOS (ARG)
COSSQ = COSPHI ** 2
SINPHI = DSIN (ARG)
1
APPARG = ARG
PART = (((((NC0(8) * COSSQ + NC0(7)) * COSSQ + NC0(6)) * COSSQ + NC0(5)) * 
+ COSSQ + NC0(4)) * COSSQ + NC0(3)) * COSSQ + NC0(2)) * COSPHI * SINPHI
ARG = (FIK - PART) / NC0(1)
COSPHI = DCOS (ARG)
COSSQ = COSPHI ** 2
SINPHI = DSIN (ARG)
IF (DABS (APPARG - ARG) .GT. 5D-10) GO TO 1
SINSQ = SINPHI ** 2
NUPHIK = KZERO * SEMAJ / DSQRT (1D0 - ECCSQ * SINSQ)
TANSQ = SINSQ / COSSQ
TANPHI = SINPHI / COSPHI
PHI = ARG / RPD
FILAT = (((((NC0(8) * COSSQ + NC0(7)) * COSSQ + NC0(6)) * COSSQ + NC0(5)) * 
+ COSSQ + NC0(4)) * COSSQ + NC0(3)) * COSSQ + NC0(2)) * COSPHI * SINPHI + 
+ NC0(1) * AGR) * KZERO
2
CONTINUE
Q = 0.5D0 - E * 1D-6
C
Q is negative east of central meridian ****
QNK = (Q / NUPHIK) ** 2
ESCS = EPSQ * COSSQ
FVI1 = (ESCS + 1D0) * 5D11
FVII1 = (((ESCS + 2D0) * (COSSQ - SINSQ) - ESCS - ESCS) * EPSQ + TANSQ + 
+ 3D0 + 5D0) / 24D-24
D6 = ((COSSQ * 107D0 - SINSQ * 162D0) * EPSQ + (2D0 + TANSQ - EPSQ + ESCS) + 
+ 45D0 + TANSQ + 61D0) / 720D-36
LAT = PHI - ((D6 * QNK - FVIII) * QNK + FVII) * QNK * TANPHI / RPD
FIX = 1D6
FX = (1D0 + TANSQ + TANSQ + ESCS) / 6D-18
E5 = ((24D0 + TANSQ + 2D0) * TANSQ - 2D0 * ESCS + 8DO * EPSQ + 5D0) / 120D-30
LON = (30 - AZONE) * 6D0 + 3D0 + ((E5 * QNK - FX) * QNK + 1D6) * Q/
+(COSPHI * RPD * NUPHIK)
ZLAT = LAT
ZLON = LON
PRINT*, 'ZLAT=', ZLAT, ' ZLON=', ZLON, ' ZN=', ZN, ' ZE=', ZE
RETURN
END